INTERNATIONAL LIBRARY

Building Stone Foundations—Masonry

By

WILLIAM S. LOWNDES, Ph.B.

MEMBER, AMERICAN INSTITUTE OF ARCHITECTS
DIRECTOR, SCHOOL OF ARCHITECTURE AND BUILDING CONSTRUCTION
INTERNATIONAL CORRESPONDENCE SCHOOLS

BUILDING STONE
FOUNDATIONS
STONE MASONRY

245 B

Published by
INTERNATIONAL TEXTBOOK COMPANY
SCRANTON, PA.

Printed in U. S. A.

International Textbook Press
Scranton, Pa.

92267

CONTENTS

NOTE.—This book is made up of separate parts, or sections, as indicated by their titles, and the page numbers of each usually begin with 1. In this list of contents the titles of the parts are given in the order in which they appear in the book, and under each title is a full synopsis of the subjects treated.

BUILDING STONE

FOUNDATIONS

STONE MASONRY

BUILDING STONE

Serial 1058-3 Edition 2

VARIETIES AND QUALITIES OF STONE

INTRODUCTION

1. Rock is the name given to the mass of minerals that constitute the crust of the earth. Small pieces of this rock such as are used in building construction or for other purposes are generally referred to as **stone.**

In order to decide which stone is best for use under given conditions, a knowledge of the different varieties employed in building construction, as well as the kinds available in any particular locality, is very essential. It is not necessary for an architect or builder to determine the exact composition of a stone, but his knowledge should be sufficient to aid him in selecting or specifying the kinds of stone best adapted to the purposes for which they are intended. This Section will give a general classification of the common building stones of the United States, with their composition and structure, and the qualities which fit them for use in buildings.

2. Stone suitable for building purposes is composed of a great number of minerals, although about 95 per cent. of the stone commonly used is composed of one or more of the following minerals: *Quartz, feldspar, mica, amphibole, pyroxene, chlorite, olivine, talc, calcite, dolomite, magnetite, hematite, limonite,* and *pyrite.*

3. Formation of Rock.—Rock has been formed in three principal ways: First, by the solidification of melted material

which formed rock such as granite and trap. Rock formed in this manner is termed *unstratified,* or *igneous;* second, by the mechanical destruction of other rock, the particles of which, together with the fossil remains of animal life, were deposited in layers in the depths of the ocean and pressed into stone by the weight of the succeeding layers of similar materials, as in the case of limestone and sandstone. Rock formed in this manner is known as *stratified,* or *sedimentary;* third, by the combined heat, pressure, and chemical action on rock already formed, resulting in the formation of such rock as marble and quartzite. Rocks formed in this manner are known as *metamorphic rocks.*

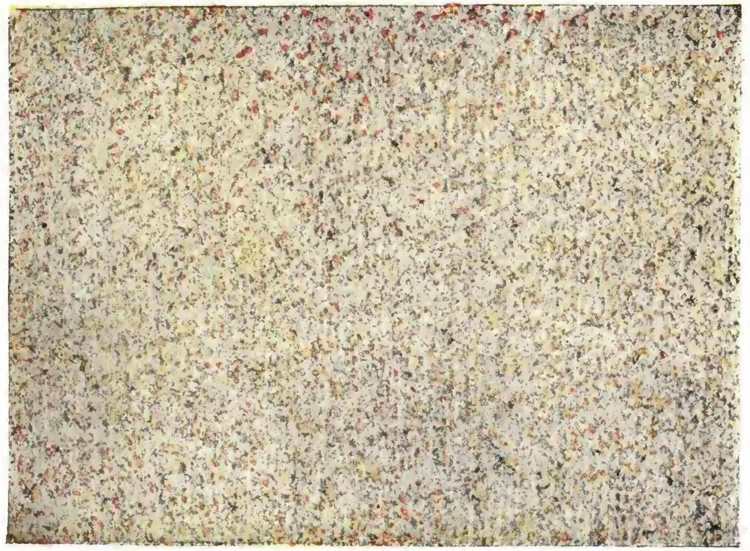
Metamorphic rock may consist largely of igneous rock, as quartzite; it may be composed almost entirely of the remains of animal life, as marble, or it may be a mixture of the two in any proportion. Metamorphic rock is nearly always stratified, or in layers.

4. Rock may be *crystalline,* in which the particles or grains are more or less regular in shape and arrangement, like lump sugar or rock salt. This crystallization is found in igneous rock, as in granite, as well as in most metamorphic rock, as in marble. The rock may be *amorphous,* in which the fine particles are of no regular size, shape, or arrangement, as in limestone and sandstone.

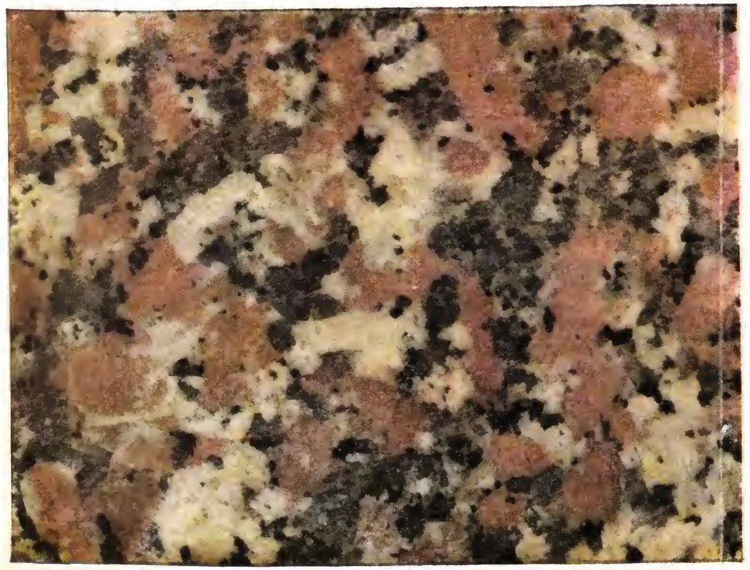
These processes of rock formation having been repeated many times in the earth's history, there is a wide variety of rocks from which stones for structural purposes may be obtained. For building purposes, however, rock may be classed as *unstratified,* or *igneous,* and *stratified,* or *sedimentary.*

UNSTRATIFIED, OR IGNEOUS, ROCK

5. Unstratified, or **igneous, rock** can be distinguished by the absence of true stratification or lamination, by the absence of fossils, and by a crystalline or glassy texture in place of an earthy texture, all of which characteristics are due to conditions in which they were formed. Igneous rock has



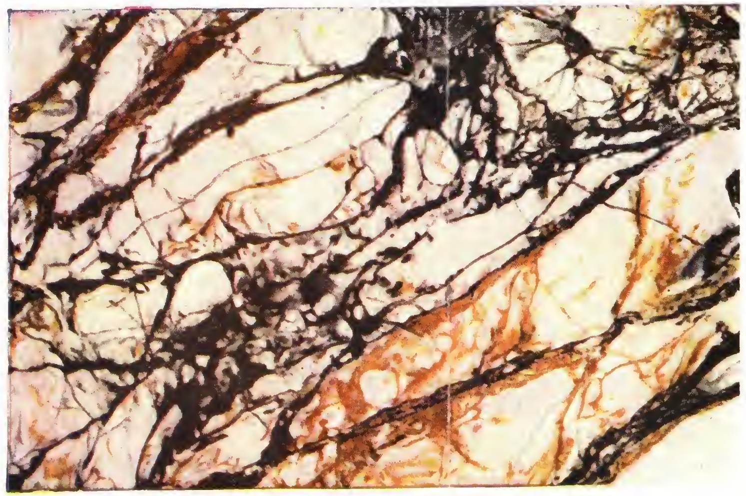
(*a*)



(*b*)

Courtesy of National Building Granite Quarries Association

BB 245 1058 BB 279 5375 Fig. 1



(*a*)

(*b*)

(*c*)

(*d*)

Fig. 3

w
th
m
to
in
th
th
m
co
fo
q
m

as
o
in
fi

a
st
re
m
ti
st

m
re
o
as

b
a
p
to

consolidated from a state of fusion or semi-fusion instead of having been deposited as sediment. Its original fused or melted condition is shown by the crystallization or glassy texture. The kinds of igneous rock commonly used for building purposes are *granite, syenite, trap,* and *gneiss.*

6. Granite consists of an aggregation of feldspar and quartz crystals together with small quantities of other minerals such as mica and hornblende, and is never found in layers or strata. The color of granite is determined by the colors of the component parts, the general tones being white, gray, yellow, and red. The quality varies also with the proportions of the component parts, the hardest stone containing more quartz and less feldspar and mica than the softer varieties. The general appearance of typical samples of polished granite may be seen in Fig. 1 (*a*) and (*b*). In (*a*) is shown a granite known as Victoria White Granite, quarried at Fitzwilliam, New Hampshire, by the Milford Pink-Victoria Granite Company. In (*b*) is shown a granite known as Moose-a-bec Red Granite, quarried at Jonesport, Maine, by the Rockport Granite Company.

7. Granite may be quarried easily, as it cleaves or splits with regularity, and can be obtained usually in any desired size. Great difficulty is experienced, however, in working the stone, owing to its hardness and toughness. These qualities make granite very expensive to cut and undesirable when much cutting or carving is to be done. Nevertheless, it can be given a high and durable polish. The facility with which granite can be split is indicated in Fig. 2, which shows a block of granite approximately 5 feet square. The holes made by tools with which the block was split may be seen plainly at *a* and *b*.

8. Granite is probably the best stone for foundations, and is used extensively in other work where great strength is required. It is also put to such minor uses as flagging, thresholds, and water tables, where durability is essential.

9. All kinds of granite are damaged considerably by the action of fire, which causes them to crack badly. The rock disintegrates at temperatures ranging from 900° to 1,000° F.

10. Granite is found in the eastern and western parts of the United States and in Canada, the gray variety occurring principally in the New England states and Virginia, while the red variety, which usually is harder, is found near the Bay of Fundy, on the islands of the St. Lawrence River, in Maine, in Virginia, near Lake Superior, and in many parts of the Rocky Mountains.

FIG. 2

11. Syenite is similar to granite, but contains no quartz, which is the distinctive element in granite. Syenite consists of hornblende and orthoclase, with sometimes mica, augite, and pyrites. It has a granular texture resembling granite, is hard, tough, and somewhat coarse-grained, but will not take a polish.

12. Trap is a rock consisting of hornblende and feldspar. It breaks into blocks with ease, but has no apparent granular

structure. Owing to the difficulty of quarrying this rock in large pieces, it is seldom used as a building stone, although it makes an excellent aggregate for concrete.

13. Gneiss is very much like granite in composition, but is distinguished from it by the absence of quartz. The particles are arranged in somewhat parallel layers, and, owing to this peculiarity, the rock splits into slabs having approximately parallel surfaces, thus making it valuable for walls, street paving, and work of a similar nature. Gneiss is called *stratified,* or *bastard, granite* by quarrymen.

STRATIFIED, OR SEDIMENTARY, ROCK

14. Probably 90 per cent. of the rock occurring in the surface of the earth is of the stratified, or sedimentary, class. The principal rocks of this class are the *limestones* and the *sandstones.*

LIMESTONES

15. The **limestones** used in building construction consist of lime in combination with one or more of the following constituents: silica, clay, talc, hornblende, mica, carbonate of magnesia, and iron. Fossil remains, such as shells and coral, usually in a more or less pulverized condition, are found frequently in limestones. The term limestone is very general, and includes many varieties that differ from one another in characteristics and qualities. As not all of the limestones are suitable for building purposes, care and experience are necessary to make the proper selection.

16. The principal limestones used for building purposes are the *common* and *magnesian limestones,* and *dolomites.* **Common limestones** are composed chiefly of carbonate of lime, and most of them contain pulverized shells and marine fossils. Limestones containing 10 per cent. or more of magnesia are called **magnesian,** and those having over 45 per cent. of that substance are termed **dolomites.** Dolomites

are crystalline and granular in structure and usually are nearly white or of a yellowish tinge.

17. In color, limestones are generally light gray, blue, or buff. Good examples are obtained from Bedford, Indiana, and Bowling Green, Kentucky. Both of these limestones are very durable, and may be classed among the best building stones. Limestones, although durable, are easily stained by smoke, are easy to work, and are easily destroyed by fire.

18. Marble is a crystallized limestone, and one of the most beautiful building materials. It is used for ornamental purposes only. It is perhaps the best known metamorphic rock, having been formed from limestone by the action of heat and pressure. Marble is generally more or less translucent, and can be obtained in many varieties, the predominating colors being white, gray, red, blue, green, and black. Most marbles show a graduation in color tone, some varieties being of several tints or colors. Nearly all varieties of marble are beautifully veined with lines or streaks of variegated colors, as shown in Fig. 3. At (*a*) is shown pavonazzo marble; at (*b*), red Numidian marble; at (*c*), dark sienna marble; and at (*d*), Alps green marble. Practically all marble will take a high polish, which brings out the colors and veinings, and enhances its value. One of the most important characteristics of marble is that it is easy to carve; the closer the grain of the stone, the more suited it is to this purpose. The white fine-grained varieties are especially prized for sculpture.

19. Some of the best varieties of white American marble are found at Lee, Massachusetts, and in the vicinity of Rutland, Vermont. The dark-blue marble from the Vermont quarries is very durable and has a fine close grain. A handsome black marble is quarried at Glens Falls, New York. Colored marbles, including gray, light and dark pink, buff, and chocolate, are found in Tennessee, Georgia, and many other places.

Holes and cracks are found very frequently in nearly all marbles, and these defects cannot be avoided, but are overcome by filling the holes and cracks with wax colored to match the

marble. The surface of the wax will correspond to the polished surface of the marble, thus concealing the defects.

20. Serpentine is a rock consisting largely of magnesia, but it also contains quantities of other materials which give it a variegated appearance. One variety of serpentine, on account of its dark color and greenish veining, is known as *verdantique marble.* The prevailing color of serpentine is green, and the tone is generally dark and somber. Because of its veinings, the stone can seldom be obtained in large pieces or cut in thin slabs. It is used for its decorative value, alone or in connection with other stone.

SANDSTONES

21. Sandstones are composed of grains of sand, usually quartz, cemented together by silica, oxide of iron, or carbonate of lime. These grains are sometimes formed into rock by fusion, or under great pressure, and such stone is nearly as hard as quartz. This variety is known as *quartzite,* and is very strong and durable.

22. When the cementing material is silica, the stone usually has a light gray color; but if the grains are cemented by oxide of iron, the stone is either red or brown and is much softer. With carbonate of lime as a cement, the result is a light-colored or gray stone, which is soft and easy to work, but which does not, as a rule, weather well.

23. Sandstones include some of the finest and most durable stones for outside construction. The ease of working them and their wide distribution cause them to be very extensively used. Sandstone is found in a great variety of colors, such as gray, brown, buff, pink, red, drab, and blue. The color depends largely on the quantity of iron oxides contained in the stone. The presence of these oxides is not injurious, but no sandstone containing iron pyrites should be used for exterior work, as it it almost sure to become stained by rust, because of the decomposition of the pyrites.

24. Sandstones vary in texture from those in which the grains are almost imperceptible to those in which the particles are several inches in diameter. The finer-grained stones can be worked more easily than the coarser varieties.

25. Quarried sandstones usually hold much water, and this renders them soft and easy to work; but nearly all become harder as the water evaporates, and the stone should not be subjected to heavy loads until the water has dried out. Cutting and carving should be done before the quarry water has evaporated.

26. Blue shale, or bluestone, is a variety of argillaceous, or clayey, sandstone with a bluish color and is found

FIG. 4

in large quantities along the Hudson River, in the vicinity of Kingston, New York. It is very hard and dense, and makes an excellent material for foundations, sills, and flagging, as it splits readily into slabs of uniform thickness. Fig. 4 shows a pile of bluestone slabs. The stone is first blocked out to the desired size by means of the drill holes *a*, after which the block is split into slabs of the required thickness. Large slabs are broken up into smaller ones by first marking them deeply with a chisel, as at *b*, after which a few heavy blows along this line will cause the slab to break.

27. Slate is a silicious clay rock, containing mica, quartz, and feldspar in small fragments. The rock has been subjected

to such action as to form it into thin layers, or laminations. This formation permits the slate to be split into thin sheets, which are used for building purposes, such as roofing. Slate is also sawn into slabs of the desired shapes, which are rubbed down to a smooth surface, and used for mantels, floor tiles, steps, flagging, school slates and blackboards, and for plumbing and electrical work.

QUALITIES OF GOOD STONE

28. No part of masonwork, from an architectural standpoint, is of greater importance than the selection of stone for structural purposes. The qualities of stone, such as its strength and durability when exposed to variations of temperature and action of the weather, and its permanence of color, are points that should be studied with care. These qualities are best determined by actual experience. The appearance of stone after it has been exposed for several years in the quarry will give a good idea of the effect of weather upon it. Buildings, in which stone from a certain quarry has been used, will in a few years demonstrate the qualities of the stone.

29. Weight of Stone.—Different kinds of stone show variations in weight. In general, sandstones are lighter than limestones, and granites are heavier than either. The weight depends on the compactness, as well as on the composition, of the stone, and may vary in different parts of the same quarry. Table I shows the average weights of stones from various parts of the United States.

30. Strength.—Whenever a stone is to be used for foundations, piers, or bearing blocks, its strength is a matter of importance. If the stone appears to be first class, its strength may be assumed to be the average strength of stone of that kind.

31. The strength of stone is generally given in terms of the weight or force required to crush it. To determine this strength 2-inch cubes of the stone are placed in a machine which is capable of exerting a great pressure. This pressure is

TABLE I

WEIGHT AND STRENGTH OF BUILDING STONES

Materials			Average Weight Pounds per Cubic Foot	Compressive Strength Pounds per Square Inch
Granite,	Colorado		166	15,000
	Connecticut		166	14,000
	Massachusetts		165	16,000
	Maine		165	15,000
	Minnesota		166	25,000
	New York		166	16,000
	New Hampshire		166	12,000
Limestone,	New York	Kingston	168	12,000
		Garrison Station	164	18,000
	Indiana, Bedford, oolitic		146	8,000
	Michigan, Marquette		146	8,000
	Pennsylvania, Conshohocken			15,000
Marble,	Pennsylvania, Montgomery County			11,000
	Massachusetts, Lee, dolomite			22,800
	New York, Pleasantville, dolomite			22,000
	Italian		168	12,000
	Vermont		167	10,000
Sandstone,	bluestone		160	15,000
	Connecticut, Middletown		148	7,000
	Massachusetts	Longmeadow, brown	142	10,000
		Longmeadow, red	149	12,000
	New York	Hudson River		12,000
		Little Falls, brown		10,000
	Ohio		139	8,000
	Pennsylvania, Hummelstown, brown			12,000
Slate			160–180	10,000

indicated on a dial that is connected with the machine, and the pressure is noted when the stone begins to crack. The amount of pressure required to crack the 2-inch cube is then divided by 4, which is the area in square inches of a horizontal section of the stone. This gives the pressure per square inch of horizontal section. Several tests are made before the average result is determined. The result is the *resistance,* or *crushing strength,* of the stone. When this crushing strength is determined, it is multiplied by the horizontal section in square inches of any other similar stone, to determine the total crushing strength of the stone.

32. In discussing the crushing, or compressive, strength of stone, it is assumed that the stone has parallel horizontal beds and vertical sides, that the bottom is firmly bedded or supported, and that the load is applied uniformly over the entire upper surface. The crushing strength of such stone varies in proportion to the size of the upper surface. For example, a stone whose upper and lower horizontal beds are 2 ft.×2 ft. in size, would require four times the load to crush it that would be required to crush a stone having beds 1 ft.×1 ft. in size. The thickness of the stone is not generally considered in figuring its crushing strength, provided the thickness is not too small or too great. For instance, a block of stone subjected to a crushing force is rarely made less than 5 inches thick and, on the other hand, should not be more than ten times the least horizontal dimension in height.

In Table I are given the crushing, or compressive, strengths per square inch of various well-known building stones.

33. Cap and bond stones for piers carrying iron columns, and the bearing blocks under the ends of girders, should be very hard and strong stones such as granite, bluestone, or hard Vermont marble. For use in such situations, the *safe bearing strength* should not be greater than one-tenth of the crushing strength. For example, if the crushing strength of Minnesota granite as shown in Table I is 25,000 pounds per square inch, in construction the stone should be designed so as to support only 2,500 pounds per square inch. In this case, the factor

of safety used is 10, or, in other words, only one-tenth of the crushing strength is used as the safe working strength.

The stones in piers for warehouses and office buildings are often subjected to loads of from 420 to 500 pounds per square inch. Stone having a crushing strength of 4,200 or 5,000 pounds per square inch should be used for this work. By inspecting Table I it will be seen that any of the stones named therein will be satisfactory. The Chicago Department of Buildings permits a maximum loading of 600 pounds to the square inch, or 86,400 pounds per square foot, on first-class granite masonry laid in Portland cement mortar. Such granite masonry would possess a crushing strength of 6,000 pounds per square inch. First-class limestone and sandstone masonry laid in Portland cement mortar is allowed a loading of 400 pounds to the square inch, coursed rubble in Portland cement 200 pounds to the square inch, coursed rubble in lime mortar 120 pounds to the square inch, ordinary rubble in Portland cement 100 pounds to the square inch, and ordinary rubble in lime mortar 60 pounds to the square inch.

The Building Code of the City of New York permits a load of 600 pounds to the square inch for ashlar masonry other than sandstone, 300 pounds to the square inch for sandstone ashlar masonry, 140 pounds to the square inch for rubble stonework in Portland cement mortar, 110 pounds to the square inch for rubble stone work in natural cement mortar, and 100 pounds to the square inch for rubble stone work in lime-cement mortar.

For other cities, the permissible load varies somewhat, according to the results observed with local stones and methods.

The manner of cutting the stone and of laying it in the wall has a greater effect on the strength of the masonry than the nature of the stone itself.

34. Color.—In places where little or no soft coal is consumed, light-colored stones may be used without any danger of becoming dirty or stained, while in very smoky cities they will get very dark in a short time. In such cases, the red or brown silicious, or flinty, sandstones are the most desirable; and next in value are the granites. The stone that retains its

natural, or native, color best is the most desirable to use; but, in localities where all classes of stone change, the one to be preferred is that in which there is the least and most uniform alteration.

Stone may be light-colored when quarried, and discolor or darken on exposure to air, while some stone becomes lighter in color on exposure to the air. Sedimentary rocks are light gray, blue, brown, buff, red, and black, while igneous rocks are usually composite in color, the general tones being white, gray, red, and sometimes green.

35. Durability.—The durability, or permanence, of stonework is of prime importance, as on this quality depends the life of a structure. It is desirable, therefore, that buildings should be constructed of the most durable stone that can be economically obtained.

Usually a stone will be satisfactory if it presents a good appearance in natural outcroppings, in long-standing quarry faces, or in buildings that have stood for some years.

36. Variations in temperature test building stone severely. Stone consists of particles cohering more or less closely. An increase in temperature expands the particles, with the result that portions of the stone are apt to separate or flake off. A lowering of the temperature contracts the particles, in which case there is a tendency for parts of the stone to separate or pull apart from the rest, forming checks or cracks. Such changes are among the most important causes of disintegration of building stone.

37. Frost has an injurious effect on stones saturated with moisture, as water in freezing expands with considerable force and dislodges particles of the stone. Repeated freezing and thawing will in time disintegrate the surface of the stone. Granite is the least porous of stones, and for this reason is best adapted for use in wet places which are exposed to frost.

38. Pure water and the dry gases of the air have but very little effect on building stone. Rain, however, often contains

traces of nitric, sulphuric, and other acids, absorbed from smoke, and other impurities in the air. These acids, when brought in contact with stone, affect its durability, through oxidation and solution of some of the mineral constituents of the stone. Where iron is present in the stone in the form of pyrites, it combines with moisture and oxygen in the air and produces the discoloration known as *rust*.

39. Carbonates of lime and magnesia are present in all marbles and limestones, and are easily acted upon by atmospheric gases, the portions of stone containing these materials being dissolved out. Sandstones containing these substances suffer also from the same cause, while granites, having practically no substances affected by acids, are least affected.

40. Heavy pounding or hammering has a tendency to destroy the cohesion of the grains of the stone and thus render it more susceptible to climatic influences. Only granite and the hardest sandstone should be peen- or bush-hammered. The most durable finish for granite is rock-faced, as the crystalline facets, being little disturbed in the dressing, shed moisture readily. For other stone, however, a smooth surface is usually the best in localities where climatic changes are frequent. Quarrying by explosives often causes cracks that are so small as to be unseen until the application of a load makes them large enough to be visible. The fracture of stones in buildings is due more often to the method of quarrying, the treatment during the cutting, and to imperfect setting, than to any lack of strength in the texture of the stone.

41. For steps, door sills, and paving, the hardness of a stone is of importance, and for these purposes granite and other hard stones are most suitable.

42. Stones of a stratified nature should be laid on their natural beds whenever possible. In other words, the stones should be laid in the wall with the layers or stratifications in a horizontal position, as they were in the quarry. If placed so that the layers are vertical, water gets in between them much more easily, and, in freezing, very quickly splits the stone.

Stones used in sill- and belt-courses that are so placed that rain washes over them, will deteriorate much more rapidly than the rest of the masonry, and on this account should always be of the most durable kind.

Stones forming the top member of a cornice as in Fig. 5 (*b*) at *l* offer a large top surface which is almost level and affords a place for ice and snow to collect. Unless covered by some waterproof covering, such as sheet copper, as shown in Fig. 5, the stone would tend to disintegrate.

43. In selecting building stone, it is often important to obtain a kind that possesses good fire-resisting properties. It should be remembered that fine-grained, compact sandstones withstand fire the best, while the exposed surfaces of limestones and marbles are converted into lime by intense heat. Granites are more affected than sandstones, and less than limestones.

44. Seasoning of Stone.—Sandstone and limestone as they lie naturally in the quarry often contain some water which is called *quarry water*. In order to evaporate this quarry water the quarried stones should be exposed to the air from four to six months before being used. This is called *seasoning* and makes the stone harder and more durable under the action of frost. It is supposed that the quarry water contains in solution considerable cementing material and that this is deposited when the water evaporates, firmly binding the particles together. It can be seen readily that all necessary cutting of the stone or carving on stone of these kinds can be done to advantage as soon as possible after quarrying, while the stone is still soft before the quarry water evaporates. After the quarry water has evaporated, the surface seems to have a film of very hard stone, which, if removed, renders the interior more liable to disintegration by weathering agencies.

45. Some contractors refuse to accept sandstone which has been exposed to freezing before seasoning. Quarries are sometimes flooded during the winter months to prevent damage from frost on quarried stone or on stone exposed in the face of the quarry.

INSPECTION AND TESTS

46. A close inspection should be made of all stone before it is used, to see that the specified quality is being delivered. When large quantities are to be used, it is even advisable to visit the quarry in order to note the quality of the stone and to determine how it is affected by weather conditions.

47. Laboratory tests may be made on samples of the stone secured from the quarry, to determine their qualities. These tests may be *chemical, microscopical,* or *physical.* **Chemical tests** determine the composition of the stone. **Microscopic examination** of thin slabs of the stone will show the mineralogical composition and the state of aggregation, the presence of impurities, amount of cementing material, and the presence of cracks. **Physical tests** determine the crushing strength of the stone. Tests of this kind are sometimes made to determine the durability of the stone under various conditions, as well as to determine the specific gravity, porosity, weight, effect of heat, effect of alternate freezing and thawing, and the action of various agencies, such as carbonic and sulphurous acids. To assist in determining the qualities of stone with reference to durability and general fitness for building purposes, the tests generally made are for *absorption, solubility,* and *compactness,* or *hardness.*

48. Absorption.—The tendency of a stone to absorb water should be considered with regard to the effect on the appearance of the building. While a dense non-absorbent stone is restored to its orginal color by a heavy rain, one of open texture will quickly absorb the water, which carries dust and soot into the pores of the stone and soils it in a short time.

Generally, the most durable stones are those that absorb the least water. In order to test the absorptive qualities of a stone, a good average specimen should be thoroughly dried, carefully weighed, and immersed in water for 24 hours. When taken out, the surface moisture should be dried off and the piece again weighed; from the gain in weight, a good idea of the value of the stone may be obtained. One that increases

10 per cent. in weight in 24 hours should be rejected, unless it can be proved that such stone has endured successfully the tests of time and weather, as described previously. One absorbing even 5 per cent. of water and containing a large proportion of clay is undesirable from the standpoint of permanence.

49. Solubility.—To determine whether a stone contains much matter that is earthy and easily soluble, a sample of the stone should be crushed finely and placed in a glass of water and the particles allowed to remain undisturbed for about half an hour. At the end of this time, stir thoroughly the contents of the glass. If the stone contains much earthy matter, the water will assume a turbid or cloudy appearance, and if it has only a small quantity, the water will remain clear.

50. Compactness, or Hardness.—The densest and strongest stones are generally the most durable. An idea of the compactness may be obtained by examining, through a good magnifying glass, the faces of freshly fractured stones. These should be clear and bright, and the particles well cemented together. A dull, earthy-looking fracture indicates liability to quick deterioration, and if the stone gives forth a clear metallic sound when struck with a hammer, it is conclusive proof of its compactness.

51. As already stated, the air in industrial communities is very likely to contain traces of various acids that attack the stone when it is washed by the rain. To determine the probable effect of acids on a particular kind of stone, soak a sample of it in a dish of water which contains a drop or two of muriatic or sulphuric acid. If there is a very noticeable bubbling, it will be wise to test the stone chemically and compare the result of the analysis with the analysis of similar well-known stones. This work should be done by a chemist or mineralogist.

Any undesirable variation in the color or texture of the stones can generally be seen by a careful inspection of the stones. Stones that are objectionable in color or too coarse in texture can be rejected and removed from the site.

STONE CUTTING AND FINISHING

52. The art of stone cutting consists of making templates or patterns from which any stone can be cut and of cutting the stones to match these templates. These templates or patterns will be described later. Stones having carefully made joints and beds and which are accurately fitted into walls or other masonry construction, constitute what is known as **cut-stone work.** The stones themselves are called **cut stone.**

Cut-stone work is, as a rule, confined to the facing of walls which are backed by a cheaper material, and when the stone is so used it is referred to as **ashlar.** The methods used to produce such stonework are briefly described in the following pages.

DRAWINGS

53. Architect's Drawings.—In designing the façade, or front, of a building that is to be finished in ashlar, the architect generally lays out all the stones on his drawings with considerable care. The stones should have a pleasing shape, and be neither too large nor too small. The drawings of some details, such as moldings, cornices, and carvings, are usually made full size, so that the intention of the architect may be clearly understood, and as little as possible be left to the judgment of the stonecutter.

54. Fig. 5 (*a*) illustrates a portion of an architect's drawing of a building front finished in cut-stone work. The joints, as well as the moldings and ornamentation which are cut on the different stones *a, b, c, d,* and *e,* are all shown. The stone *f* is cut to receive the arch stone *g*. At *h* is shown a section through the stone jamb, indicating the form of the molding which is to be cut on the jambs of that window.

55. In (*b*) is shown a section through the front of the building on the line *x–x,* Fig. 5 (*a*). This line cuts the key-

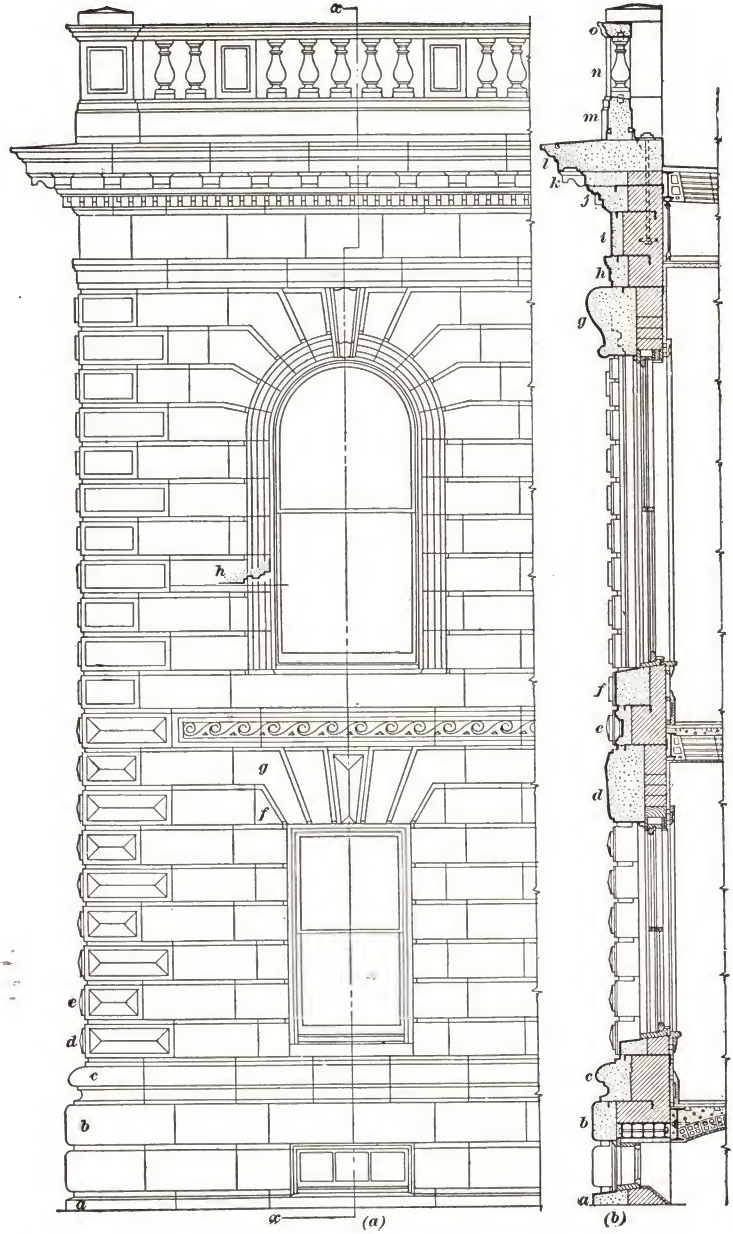


Fig. 5

stones of the arches in the first and second stories, and also the lintel over the basement window. A section through the basement sill is shown at *a*, and through the basement lintel at *b*. At *c* the section line cuts the string-course below the first-story window sills. A section through the keystone of the arch over the first-story window is shown at *d*, while *e* shows a section through the string-course below the second-story sill *f*. A section of the keystone of the arch over the second-story window is shown at *g*; and it will be noted that the outline of the jamb is shown in dotted lines at this point,

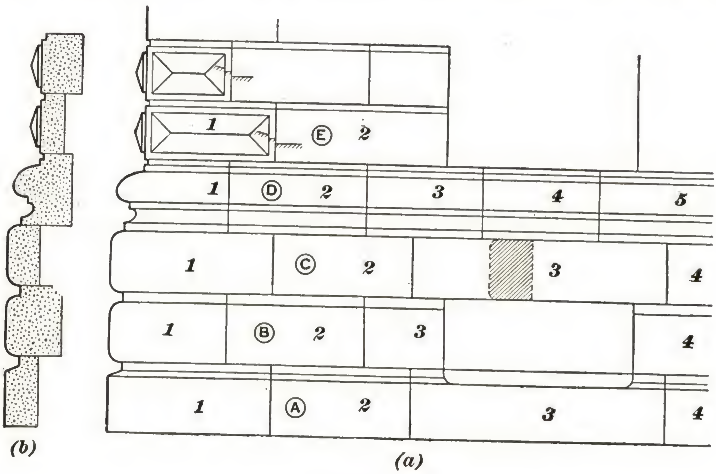


FIG. 6

as the circular jamb fits against the keystone. A section of the entablature is shown at *h, i, j, k,* and *l* and above this is a section through the balustrade at *m, n,* and *o*.

56. Stonecutter's Drawings.—From the architect's drawing, Fig. 5, the stonecutter makes a drawing, a portion of which is shown in Fig. 6, from which the stone is cut and also from which the stone is set in the building. In this drawing, in (*a*), each course is given a letter, beginning with *A* at the bottom course. The stones in each course are numbered from left to right, each being given a specific number as shown in the figure. This number, and the letter showing the course

are painted on the back of the stone for identification. When several of the stones are identical in shape and finish, the marking is sometimes repeated for each of them, so as to avoid the use of high numbers, and to avoid the necessity of looking for a stone having a particular number when there may be many others of the same size and finish available. A section through the cut-stone work is shown in (*b*).

57. Templets.—A *templet,* or *pattern,* is made for each different design of stone, and consists of a form cut out of sheet metal, cardboard, or heavy paper, showing the profile of any moldings or recesses in the stone. In Fig. 7 is illustrated a templet such as would be used for the stone course *A* in Fig. 6. This templet shows the profile of the exposed cut surface of all similar stones in this course. In laying out a stone, the top and bottom surfaces *a* and *b* are made parallel and straight, and the shape of the templet is marked on the end of the stone. The stone is then put into the planing machine, which will be described later, and is cut to this profile throughout its entire length. A similar templet is shown in Fig. 8 for the stone in the course *D* in Fig. 6. Special templets are made for the stones with special shapes, such as the keystone in the second-story window. The shapes or profiles of all these special stones are obtained from the full-size drawings, which are made in the architect's office and sent to the stonecutter for his guidance.

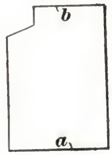


FIG. 7


FIG. 8

CUTTING STONE BY MACHINE

58. Most of the cutting of stonework for buildings is done in stone yards by machines. These machines are arranged generally in one of two different ways. In one case they are arranged in a rough circle around a central derrick, as shown in Fig. 9. In this figure the arrangement of the yard is roughly indicated, with the various machines located at *a, b, c, d,* and *e,* and piles of stone at *f, g,* etc. All of these are readily reached

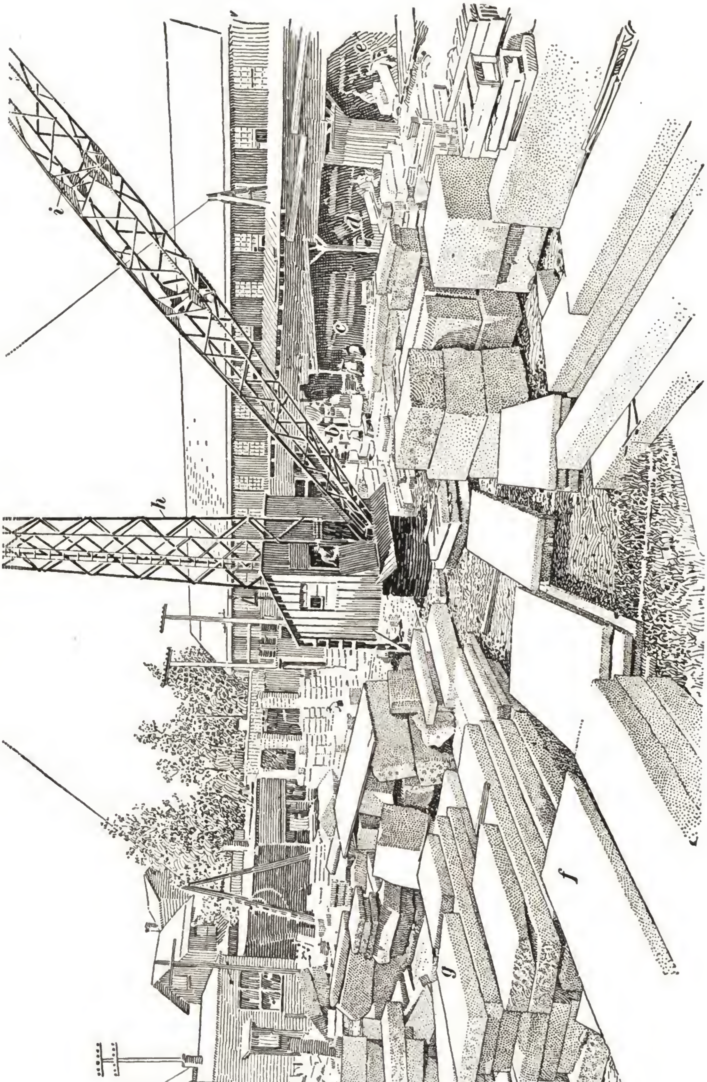


FIG. 6

by the derrick *h,* which, by means of the boom *i,* lifts the stone from the piles at *f* and *g* and deposits it on the beds of the various machines and also removes the finished work from the machines and deposits it on the wagons to be shipped away, or in other positions where further cutting may, if necessary, be done upon it. Another type of stone yard or shed is that in which there is a traveling crane which moves back and forth along the length of the yard or building. In this case, the machines may be placed at any convenient point in the building and still be properly served by the crane. The principal machines used in stone cutting are *saws, planers, lathes, grinders, polishers,* and *pneumatic tools.*

SAWS

59. Gang Saws.—The gang saw illustrated in Fig. 10 is one generally used to cut rough stone into small portions and is used particularly on hard stone like granite. These machines

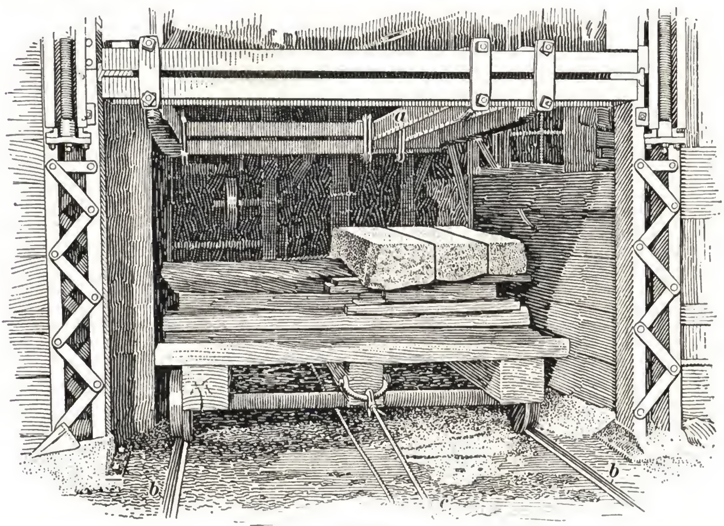


FIG. 10

consist of saws *a,* which are long bands of steel with their edges cut to form rectangular teeth. These saws are drawn back and forth through the stone in the same manner as a

carpenter's hand saw, the work, however, being done by power. The stone is firmly supported by wooden blocks upon a bed, or truck, which runs on tracks *b*, and is pulled back and forth by means of ropes *c*, attached to the platform. When the stones have been cut as shown in the figure the saws are raised, the truck is pulled out from under the saw, and the pieces removed from the platform by means of the derrick. While the saws are working in the cuts in the stone, hardened steel shot is introduced in these cuts, and assists in cutting the stone. Water is poured continually into the cuts to absorb the heat

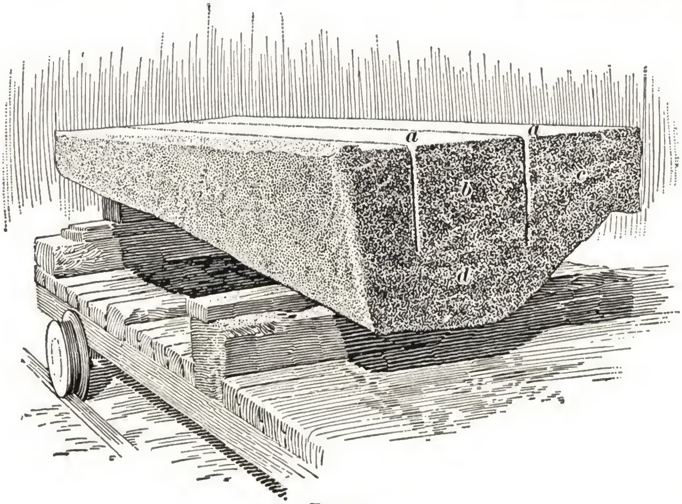


Fig. 11

generated by friction and also to remove the stone dust from the cuts. Fig. 11 shows the other end of the stone shown in Fig. 10, after it has been machine-sawed and withdrawn from underneath the saw. The saw cuts *a* are deep enough to furnish the stones *b* and *c*, of the required size, and to permit the stonecutter to split the block along the line of the saw cuts. The material below the saw cuts, as at *d*, is superfluous material which will be discarded when finishing the stones to size.

60. Diamond Saws.—Diamond saws are circular blades of steel, in the edges of which are placed diamonds of a black

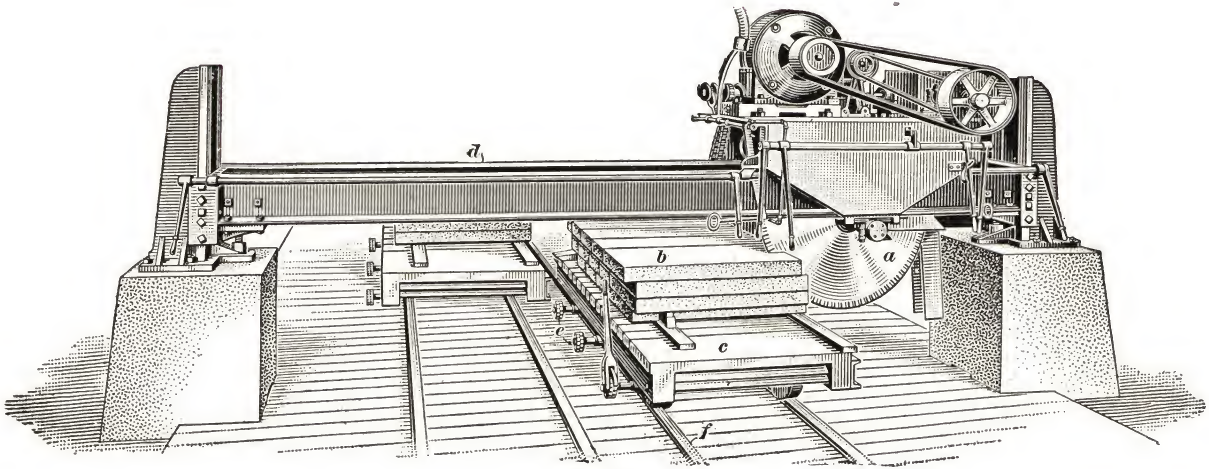


Fig. 12

ish color. These diamonds take the place of the teeth of the ordinary saw and, when the saw is revolved rapidly, the stone is cut with great facility and speed. Such a saw is shown at *a* in Fig. 12. Four slabs of stone *b*, on a truck *c*, are being cut at one operation. The saw is arranged to travel across the frame *d* of the machine, and the truck may be locked by the brake *e* to the rails *f* at any desired point.

In another style of machine, Fig. 13, the stone *a* is fastened to a bed *b*, which travels past the saws *c*. The saws may be moved to any point on the supporting member *d*, which may

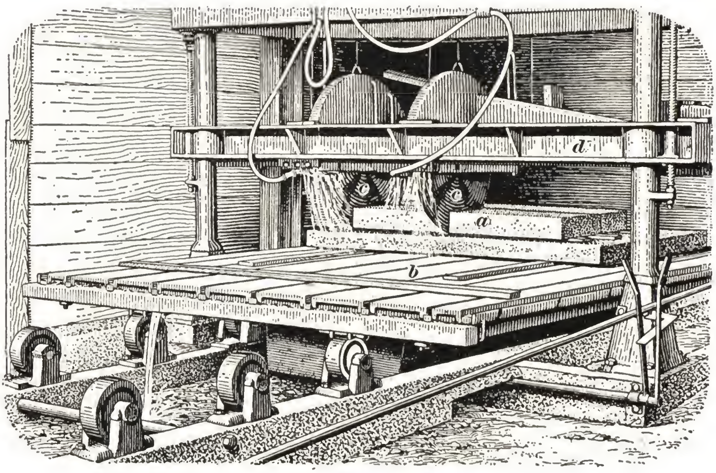


Fig. 13

be raised or lowered as desired. Streams of water directed against the sides and edges of the saws keep them cool.

61. Carborundum Saws.—Carborundum saws are circular saws of steel which have teeth made of carborundum instead of being fitted with diamonds. These saws are very effective and are used in the same manner as diamond saws.

62. Band Saws.—Band saws are similar to the band saws which are used for woodwork, the cutting edge running downwards in a vertical direction. The cutting is done by the aid of sand or carborundum, and water, that are introduced into the cut during the sawing process.

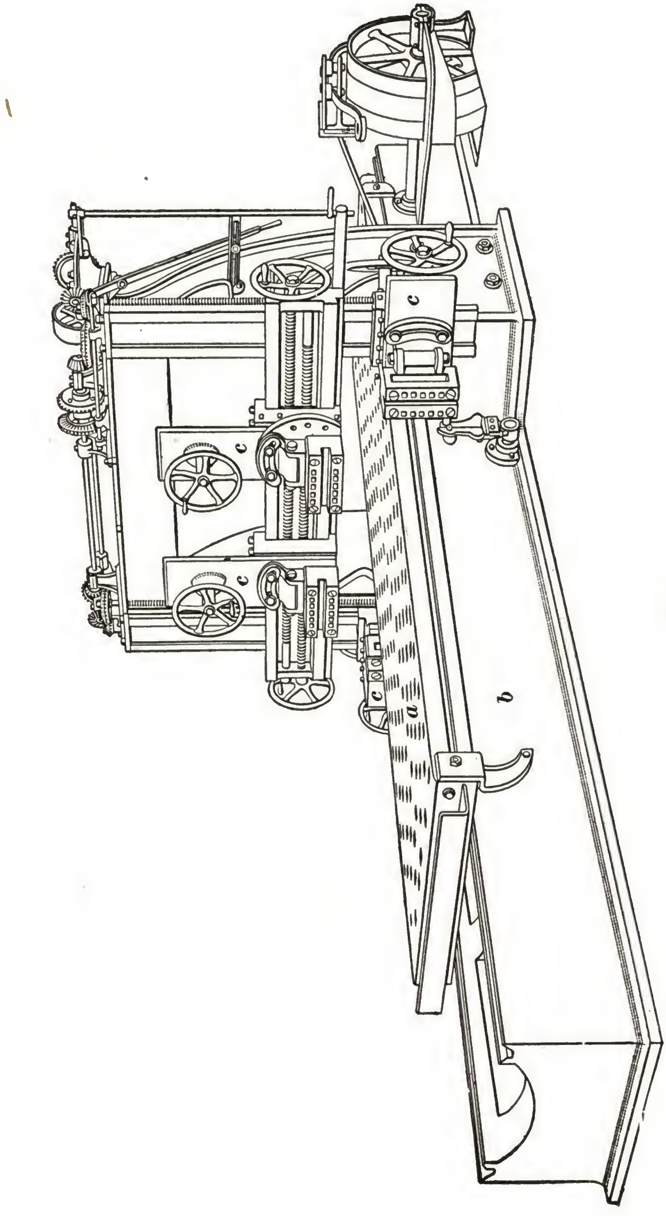


Fig. 1

PLANERS

63. A **planer** consists essentially of a heavy sliding bed of steel *a,* in Fig. 14, on a foundation *b.* To the bed *a,* the stone to be planed or molded is securely fastened by blocks which are inserted in holes in the plate. Tools suitable for cutting the molding required are firmly held in the heads *c,* and the plate *a* is set in motion, forcing the stone against the edges of these tools, thus scraping off the surfaces of the stone to the desired shape. These tools can be moved up or down or sidewise as may be desired. Planers are used generally where

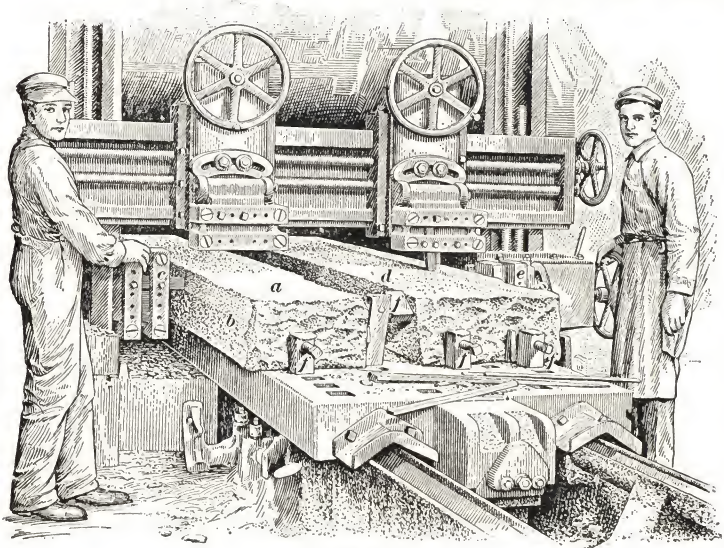


Fig. 15

the moldings or surfaces are perfectly straight, but where moldings are to be run on a curved surface the work may be done on a somewhat similar machine arranged to do that kind of work. In Fig. 15 two pieces of stone are being planed at one time, on a machine similar to that shown in Fig. 14. The stone *a* has the top surface finished and the side *b* is being finished by the tool *c.* The stone *d* has the tool *e* dressing the side, while a similar tool is finishing the face or top. The stones are held in place by the blocking at *f.*

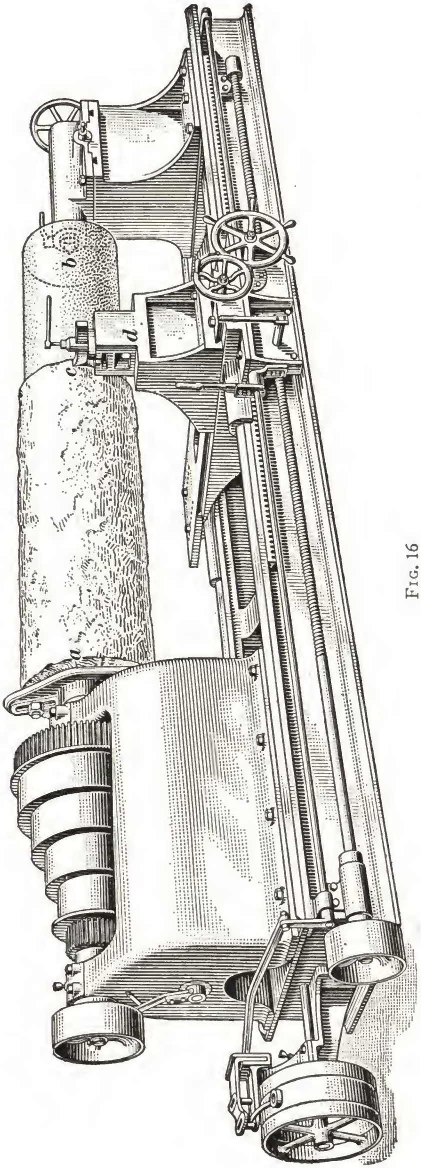


Fig. 16

LATHES

64. One style of **lathe,** shown in Fig. 16, may be used for turning columns, balusters, and similar work. The stone, held between the centers of the headstock *a* and the tailstock *b,* and revolved against the cutting tool *c,* inserted in the toolpost *d,* is pared down to the required size. Lathes are made in various sizes, the one shown being capable of turning colums 66 inches in diameter and 24 feet long. Attachments are provided for fluting when desired.

POLISHERS

65. One form of **polisher,** or **polishing machine,** is illustrated in Fig. 17. This machine consists of a pedestal *a* and a horizontal arm *b.* On the lower extremity of this arm is a disk *c,* which is fitted with carborundum blocks. This disk is revolved rapidly by means of belts worked on the

pulleys *d*. The belts are omitted from this figure for the sake of clearness. The rapidly revolving disk is applied to the surface of the stone *e*, as shown, and can be moved to any part of the stone by means of the handle *f*, thus polishing the entire surface of the stone.

Another type of polishing machine consists of a fixed bed similar to that used in a planer, to which the stone to be pol-

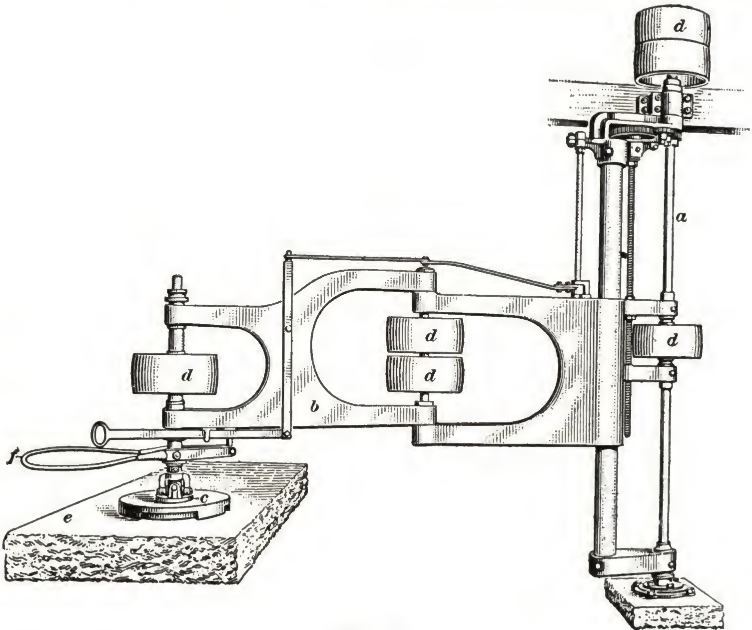


FIG. 17

ished is secured by blocks and wedges. Circular disks having carborundum surfaces are revolved rapidly over the surface of the stone, producing the desired polished or rubbed effect. Machines of this type are used principally for polishing granite and marble.

PNEUMATIC TOOLS

66. Pneumatic tools, shown in Figs. 18, 19, 20, and 21, are used to a large extent in modern stone yards, especially for cutting granite, marble, and bluestone. Pneumatic tools, as

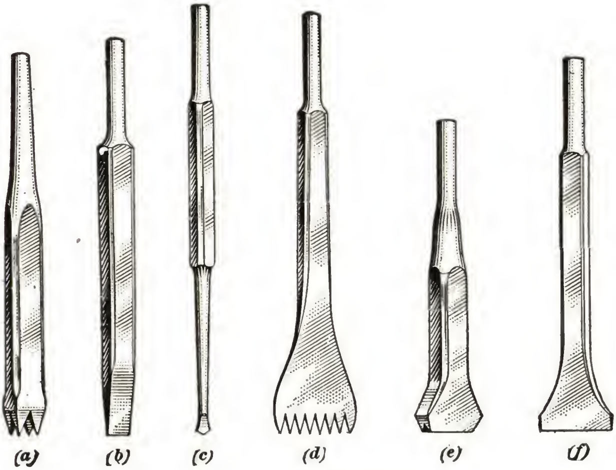


Fig. 18

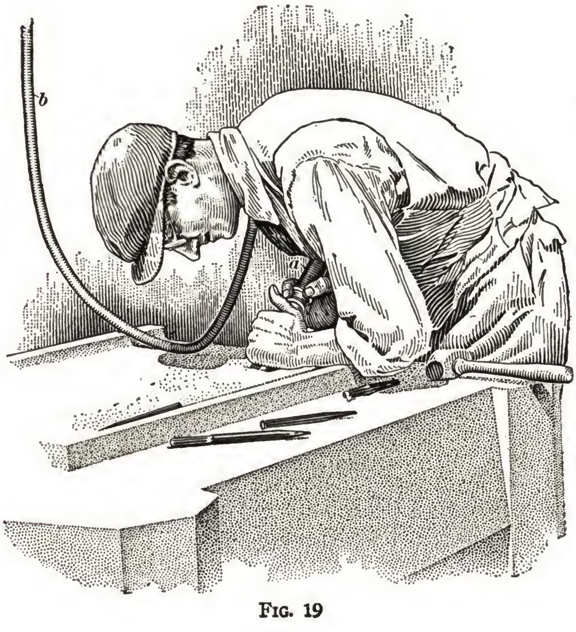


Fig. 19

shown in Figs. 19 and 20, consist of steel cylinders *a*, with movable pistons or hammers worked by air pressure, connected with air-compressing engines by means of a stout hose *b*, through which the compressed air is conveyed. Tools of various types are shown in Fig. 18, and these tools can be placed in the opening in the cylinder and driven by a succession of extremely rapid blows which cut the stone much more rapidly than it can possibly be done by hand.

In (*a*), Fig. 18, is shown a *tooth chisel;* in (*b*), a *plain chisel;* in (*c*), a *carver's drill;* in (*d*), a *marble tooth chisel;* in (*e*),

Fig. 20

a *double-bladed chisel;* in (*f*), a *cleaning-up chisel;* and in (*g*), a *bush chisel.* The general method of using these tools may be seen in Figs. 19 and 20.

67. A heavier type of pneumatic tool or stone dresser mounted on a pedestal is shown in Fig. 21. The tool holder *a* may be moved to any part of the hinged arm *b*, which may be raised or lowered on the pedestal *c*. This form of mounting takes the weight of the device from the operator and allows him to give his whole attention to directing the edge of the cutting chisel *d* to any part of the stone to be dressed.

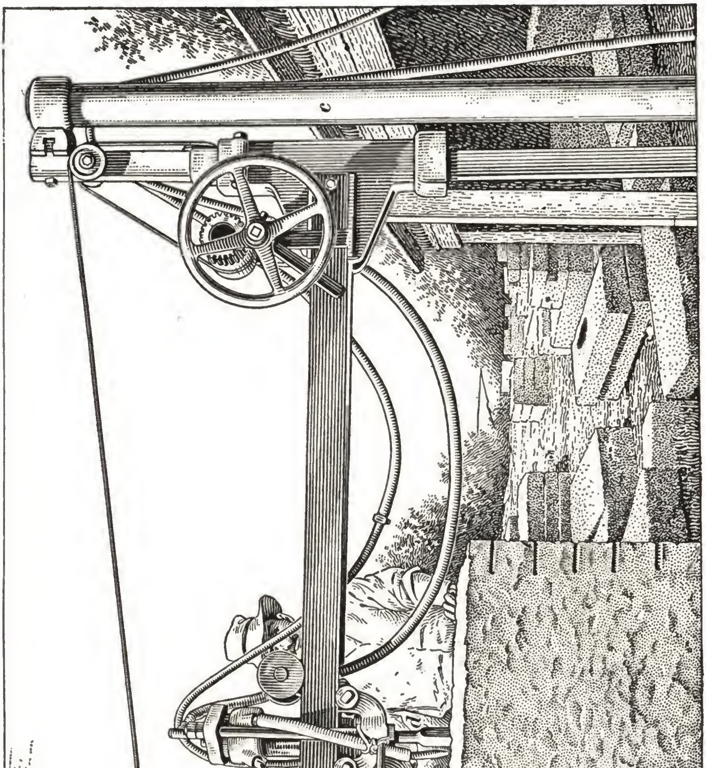


FIG. 21

68. Pneumatic tools, while suitable for granite, marble, and bluestone, are not considered satisfactory for use on very soft stones, as the action of these tools is rather severe for these stones. Pneumatic tools are used sometimes, however, for roughing out the softer stones.

CUTTING STONE BY HAND

69. As far as possible, the stone is cut by machinery. There are, however, cases where it is necessary to do considerable cutting by hand. Round or curved work in limestone is generally cut with hand tools. Hand tools are also used in fitting stones as they are about to be placed in the building after having been delivered from the stone yard. On a good-sized building one or two stone masons are kept busy constantly, cutting and fitting stones for the masons to set when they are erecting the stonework on the building. This is necessary, particularly on a building having a steel framework, where the backs of the stones must be cut out to fit in against the steelwork. A brief description of some of the hand tools that are used for cutting stones at the building and in the stone yard is given in the following pages.

HAND CUTTING TOOLS

70. Hammers and Mallets.—Masons' hammers are made of steel and are used for breaking and roughly shaping the stones as they come from the quarry. The **double-faced hammer** is shown in Fig. 22 (*a*) and weighs from 20 to 30 pounds. The **face hammer,** shown in (*b*), is a lighter tool than the double-faced hammer, weighing from 12 to 16 pounds, and is used for the same purposes as the double-faced hammer when less weight is required. It has one blunt and one cutting end, the latter being used for dressing the stones roughly preparatory to using the finer tools.

The **stone pick** shown in (*c*) is used for dressing the softer stones coarsely; its length is from 15 to 24 inches, and the thickness at the eye is about 2 inches.

The **peen hammer** shown in (*d*) is about 10 inches long, and has two cutting edges about 4 inches in length; it is used for making *drafts,* or margin lines, around the edges of stones, and for dressing the faces.

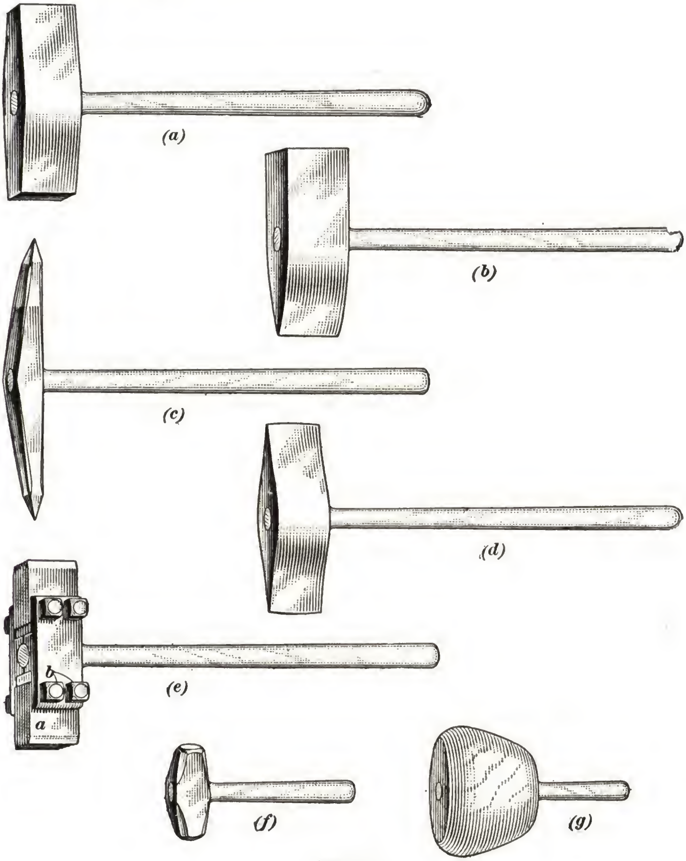


FIG. 22

The **bush hammer** shown in (*e*) is made of from four to ten thin blades of steel *a*, which are ground to an edge and held together by bolts *b*, so as to form a single tool. This hammer is used for finishing granite or hard limestone. The number of blades to the inch determines the fineness of the cut, which is specified as four-, six-, eight-, or ten-cut.

In (*f*) is shown a **mason's hand hammer,** which weighs from 2 to 5 pounds and has a short handle. It is used with

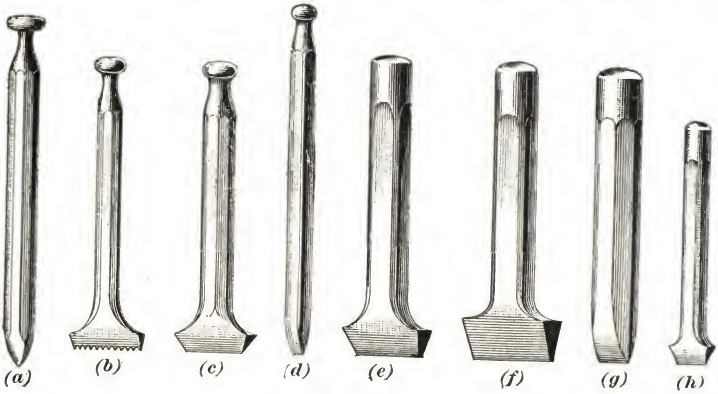


Fig. 23

various tools for drilling holes, and for pointing, pitching, and chiseling the harder stones.

The **mallet** shown in (*g*) is used in cutting soft stones. It is made of hickory wood, the head being about 7 or 8 inches in diameter and 5 or 6 inches in height.

71. In Fig. 23 (*a*) is shown a **point,** which is a tool made of round or octagonal steel, 8 to 12 inches long, with one end pointed. The point is used in chipping off the rough faces of the stone and reducing them to approximately plane surfaces.

The **tooth chisel** shown in (*b*) is used on marble and sandstone to reduce the surfaces that have been partially leveled by the point.

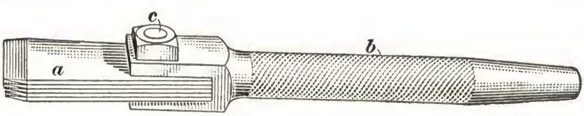


Fig. 24

In (*c*) is shown a **pitching tool,** made of steel, $\frac{3}{4}$ to $1\frac{1}{4}$ inches in thickness. It is used to form straight edges on stones.

In (*d*) is shown an ordinary **chisel.** Chisels are used in smoothing off the rough surfaces of stone and are made with cutting edges that are from $\frac{3}{4}$ to $1\frac{1}{2}$ inches in width.

The tools shown in (*a*), (*b*), (*c*), and (*d*) have *mallet heads* and are driven by means of the mallet. Other forms of chisels with plain heads are shown in (*e*), (*f*), (*g*), and (*h*) and are driven with steel hammers.

The **hand bush chisel** shown in Fig. 24 has a number of blades *a* held in the shank *b* by means of the bolt *c*, and is used in places that cannot be reached with the bush hammer.

FINISH OF STONEWORK

72. In the architect's drawings the stones and the joints between them are shown. The stonecutter makes a detail of each stone and cuts it to fit exactly against the adjacent stones. The finish of the exposed surfaces of the stones is specified by the architect. A few of the more common finishes that are specified will be described in the following pages.

73. Rock-Faced Work.—In Fig. 25 is shown **rock-faced,** or **pitch-faced,** work, and the method of using the pitching chisel. The face of the stone is left rough, just as it comes from the quarry, and the joints, or edges, are pitched off to a line, as shown at *a*. As very little work is required for this finish, rock-faced dressing is cheaper than any other kind, especially when granite, bluestone, or hard limestone is used. Care must be taken, however, that no tool marks show on the finished surface of the stone. An example of rock-faced bluestone is shown in Fig. 26. The methods of laying up this work are treated in another Section.

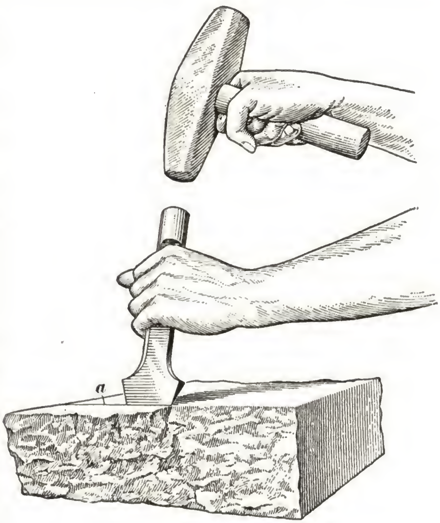


Fig. 25

Fig. 26

74. Pointed Work.—An example of **pointed work** is shown in Fig. 27. This effect is produced by taking off the

Fig. 27

projections of the stone by the use of the point. After the stone is worked over a few times it will present a rough sur-

Fig. 28

face, as shown in this figure. This work is called **rough-pointed.** If, however, the work is gone over several times

more with the point, a finer effect is produced, such as shown in Fig. 28, which is known as **fine-pointed work.**

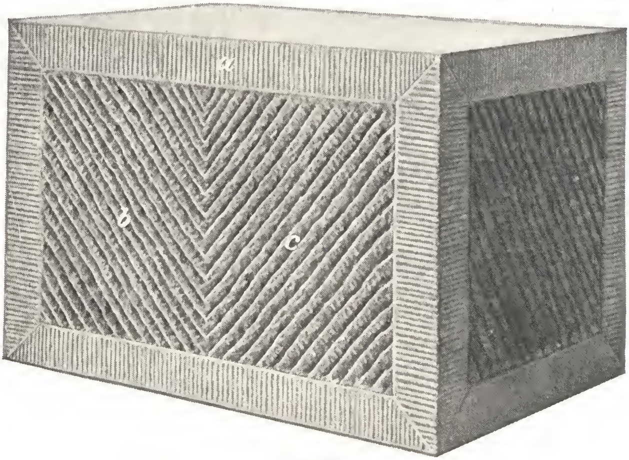


Fig. 29

75. Margins.—Building stones are sometimes faced an inch or more from their edges as shown in Fig. 28, and at *a*

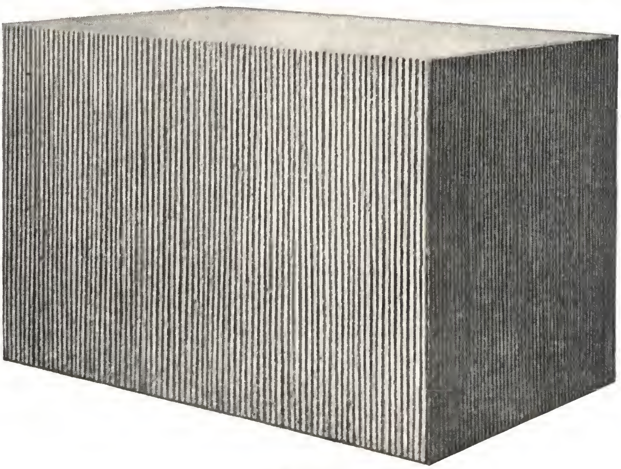


Fig. 30

in Fig. 29. This facing is known as a **margin,** or **draft.** On soft stone, this margin is cut with a chisel, but on very hard

stone, such as granite, it is cut usually with an ax, or peen hammer, in which case the surface would be plainer than the chiseled work and without the well-defined parallel channeling.

76. Broached Work.—Fig. 29 illustrates what is sometimes called broached work. In this kind of work the stone is dressed with a point, so as to leave continuous grooves over the surface. At *a* is shown the margin, and at *b* and *c* the broached center, which is cut in opposite directions in order to illustrate right- and left-hand broaching, respectively.

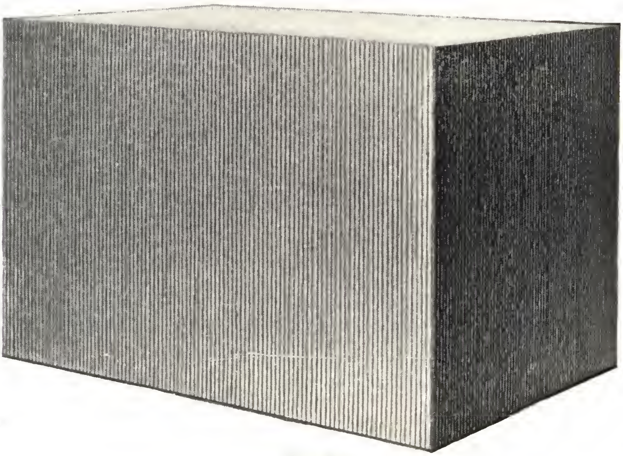


FIG. 31

77. Tooled, or Drove, Work.—Tooled, or drove, work is illustrated in Figs. 30 and 31. This class of work is generally done by machine and shows a regular and even appearance, as in Fig. 31. It may also be done by hand, in which case it has a somewhat more irregular and possibly more pleasing effect, as shown in Fig. 30. Drove work is described as six-cut, eight-cut, and ten-cut, according to the number of grooves to the inch.

78. Rubbed Work.—Sandstones and most of the limestones are often finished by rubbing their surfaces until they

are perfectly smooth. By continuing the rubbing long enough, granite and marble can be given beautiful polishes. Rubbed work is finished either by hand, using a piece of soft stone with water and sand, or by a machine which performs the same operation. If the rubbing is done soon after the stones are sawed into slabs and are still soft, it is cheaply and easily performed, as the sawing makes the face of the stone comparatively smooth. This kind of finish is shown in the plain surfaces around the carved panels in Figs. 39, 40, and 41.

FIG. 32

79. Bush-Hammered Work.—A stone finished by a bush hammer or pneumatic bush chisel, which is generally used on granite and hard limestone, is shown in Fig. 32. The stone is first dressed to a fairly smooth surface and then finished with the bush hammer. The degree of fineness in the finish is determined by the thinness of blades in the hammer, the usual number being eight or ten to the inch.

80. Vermiculated Work.—In Fig. 33 is shown a stone having a somewhat elaborate finish, which is known as vermiculated, from its worm-eaten appearance. Stones so cut are used principally as quoins and in base courses. Owing to the

cost, this dressing is not often used in the United States, except for very expensive work.

81. Rusticated Work.—Two examples of rusticated work are illustrated in Figs. 34 and 35, the former showing

Fig. 33

the stones with sharp edges and the latter the stones with rounded edges. The joint should always be at the upper edge of the rustication as shown at *a* in each illustration, as it is better protected from the weather when in this position. If the joint were placed at the lower edge of the rustication,

rainwater would lie on the lower horizontal surface and be liable to work its way back into the joint. The projection above the joint throws a heavy shadow at this point and strongly emphasizes the courses. The use of rustication is further illustrated in Fig. 5.

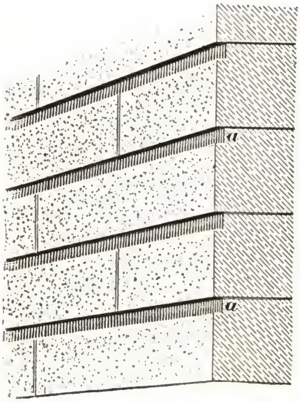


Fig. 34

The height of the rustication should bear some simple proportion to the total height from joint to joint, and should not ordinarily be less than one-sixth of that height. The depth of the rustication should be about two-thirds of its height if the edges are square, as in Fig. 34; if the edges are rounded, as in Fig. 35, the depth should be equal to the height. The rustication is sometimes obtained by **V** joints, wherein the edges of the stone are chamfered or splayed. Rusticated masonry is sometimes laid with close vertical joints, as in Fig. 34, but is more frequently laid with the vertical, as well as the horizontal, joints rusticated, as in Fig. 35. The latter method gives the better effect when the stones are of good length.

Rusticated work is used in massive buildings, usually for the first story, forming a heavy base treatment strong in shadowed joints, on which is placed the lighter and more ornate upper stories, where the joints are close or, if rusticated, very much smaller than those below. The surface of rusticated stonework is usually dressed in such a way as to give a rough appearance; this may be done either in rough-pointed, fine-pointed, or vermiculated work, as shown in Figs. 27, 28, and 33, respectively. These surfaces form a

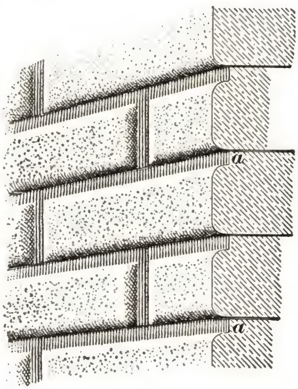


Fig. 35

pleasing contrast with the plainer surfaces of the stones above. Good examples of rusticated masonry are to be seen in the Italian palaces of the Renaissance period.

CARVED WORK

82. The preparation or cutting of stone surfaces has been taken up, and thus far rough rock faces and dressed faces, such as fine- and rough-pointed, bush-hammered, vermiculated, etc., have been considered. The final step in the elaboration of stone is **carved work.** This requires more skill than common surface finishing, and in fact is an art requiring the skill of the sculptor. A close relation exists between stone dressing, as already described, and stone carving, to be described. The same tools are used, but, in general, less attention is paid in carving to securing an even surface than to the artistic effect of each line or surface.

83. The object of stone carving is to embellish the building, to bring out the color and the attractiveness of the stone, and to give the building individuality from the nature of the decoration. Carving, therefore, as distinct from stone dressing, is employed for individual stones or masses of stones.

84. Carving was originally applied to that ornament which was cut by hand. As machines now do the work, or assist in the work which was formerly done by hand, the former distinction will no longer apply. In general, therefore, the term carving is applied to the individual decoration by cutting of various stones.

85. Carving may be done on the solid block, on surfaces dressed by the methods described, or on moldings which have been cut by the machines mentioned. The carving may be done in the shop, on the site of the building, or on the façade after the exterior of the building is otherwise complete.

86. Work which can be carved in small pieces, so as to be readily handled and set without danger of breakage, is

usually done in the shop, where tools and material provide every facility in the way of cutting and handling.

87. Some stones are carved on the ground near the building when there is sufficient space and the nature of the building will permit the setting of the stone as the work progresses. This method of cutting overcomes the risk incident to transportation.

88. Elaborate carving on large blocks, such as groups of figures or statuary, sustains too great a risk of breakage to be done by either of the methods mentioned. In such cases, the rough block of stone, or the stone roughly dressed to the approximate shape of the finished ornamentation, is set in place, and the carving done from a scaffold after the danger of damage is past. This refers particularly to large carvings with considerable projection near the base of high buildings, where quantities of materials will be hoisted past them, or where materials are apt to fall on the finished work and damage it beyond repair.

89. The softer stones, such as the limestones and marbles, being more easily worked, are more generally used for carving, as the expense is much less than when the granites and hard sandstones are employed. Care must be taken also to employ for carving, stones having a uniform texture and hardness throughout, as well as those which will stand the weather well. Great quantities of Indiana limestone are used for carving in the United States.

90. The scale and the minuteness with which carving should be executed depends on its height from the point or points from which it will be seen. Work that will be close to the eye of the observer should be carved out in great detail and fineness if the texture of the stone will permit it, while work at some height from the eye to be effective should be bold and coarse in treatment. The latter point is often overlooked, and minute carving, beautiful in itself when viewed at close range, loses its effectiveness when placed at such a height that much of its detail is lost.

91. In general, the same tools already described for stone dressing are used for stone carving. For some stones the tools may be adapted to particular uses, and, especially for marble, smaller and finer-edged tools are required for more delicate carvings.

92. Carving is usually done from full-size drawings prepared in the architect's office, or from models prepared for the approval of the architect or owner of the building.

93. Instead of making templets of all the work, the stonecutter often resorts to expedients which will shorten the labor

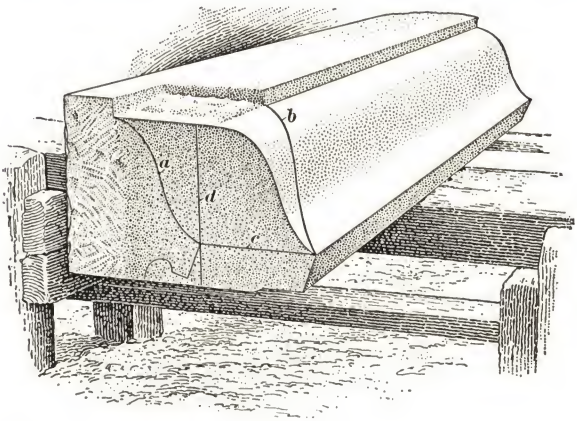


Fig. 36

of preparing the stone for cutting. When the detail is a simple one and the drawing has been made full size by the architect, the detail is sometimes drawn on the end or face of the stone. An instance of this character is shown in Fig. 36. The pencil lines *a, b,* and *c* may be seen where they have been drawn ready for the stonecutter to cut the internal angle. The line *d* is used in laying out the profile of the molding *a*. A similar stone, cut to the lines marked, and ready to set in the building, is shown in Fig. 37.

94. Where the detail is a little more elaborate, the lines of the architect's full-size drawing are sometimes pricked through

the paper with a fine needle at close intervals. The drawing is then laid on the stone and fine charcoal or graphite is sprinkled over the drawing. Sufficient of the material sifts through the holes to locate the lines so that they can be drawn in pencil on the stone. Care in laying out the design is essential to a satisfactory carving.

95. Models in clay are frequently prepared, in order that the architect, the owner, and others may judge of the appearance of the finished work. Plaster casts are made from these models and are used by the stonecutter in place of drawings. The plaster cast is used in preference to the model, as it is

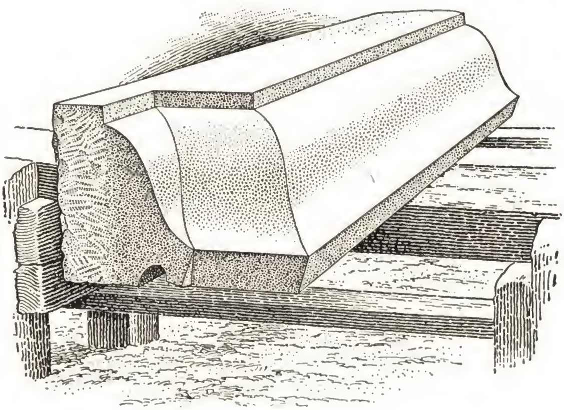


Fig. 37

lighter in weight, and if damaged can be replaced. The expert carver can successfully reproduce the plaster model in stone. Definite rules cannot be laid down for measuring or laying out this class of work, the eye of the carver being trusted usually to reproduce faithfully the lines of the model from which he works.

96. The ornament is roughly blocked out by means of the point (*a*), Fig. 23, followed by chisels or other tools that will bring the work to the proper outline with the least number of cuts. A variety of surface and background textures are possible by the use of the various tools already mentioned.

97. A large portion of the cornice of a building is sometimes made in one piece, as in Fig. 38, which shows a workman cutting or carving by hand the sides of the dentils in the course *a,* which cannot be made on the planer. The finishing of this course is all the handwork required on this cornice.

98. When carved work is set in the building before the completion of the building, it should be boxed or covered with boards to protect it from any possible damage.

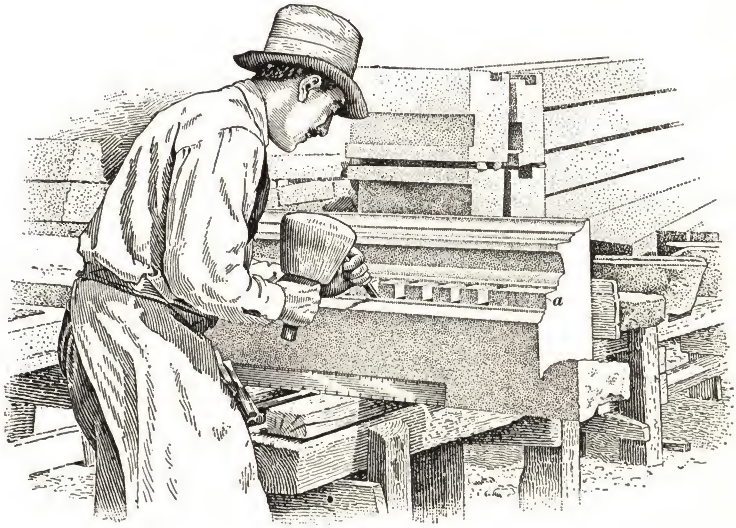


FIG. 38

99. Besides figure work, carved ornament is utilized for the decoration of plain or molded band-courses, capitals and bases of columns, pilasters, balustrades, friezes, panels, etc. Conventional or naturalistic plant and animal forms, as well as geometrical forms, are used as motifs for these ornaments. Figs. 39, 40, and 41 illustrate specimens of work executed on the City Hall of Philadelphia, Pennsylvania.

100. In Fig. 39 is shown an example of naturalistic carving in *alto-* or high-relief, and in *bas-,* or low-relief. The forms used are plant and bird life. The two plants represented are

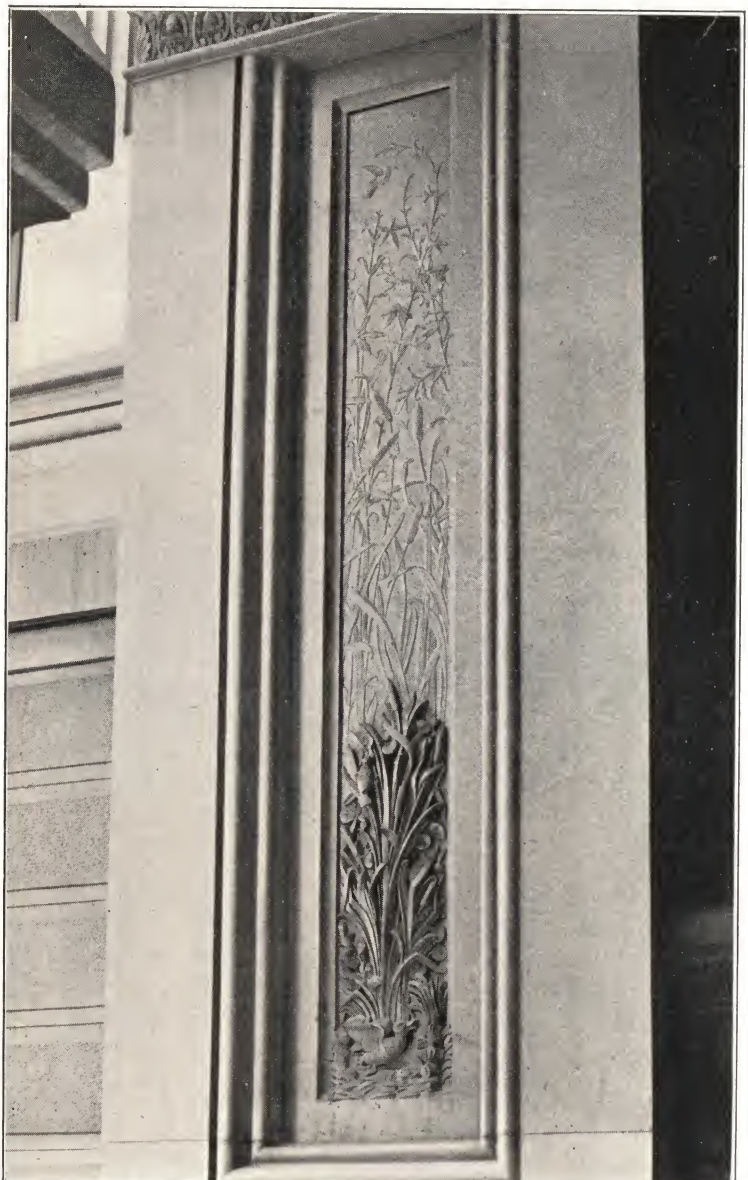


Fig. 39

FIG. 40

Fig. 41

FIG. 42

FIG. 43

Fig. 44

the *Nuphar advena,* or water lily, and the *Typha latifolia,* or common cattail. Both of these motifs are copied closely from nature, and the detail is minutely carved, as the work is placed only a slight distance above the eye. The carving near the bottom of the panel is in alto-relief and that in the upper portion is in bas-relief. The stone here used is marble, and the broad expanse of plain surfaces about the carving sets it off and frames it well. Coarse-grained stone, owing to its rough texture and the size of the particles, would not be suitable for such delicate carving.

101. In Fig. 40 is illustrated a similar panel in which the natural forms copied are the foliage and fruit of the oak and the mistletoe, with squirrels perched on the limbs. This is a most beautiful piece of work and is very realistic. The distribution of the different treatments of relief is the same as in the previous example.

102. In Fig. 41 is shown a conventional scroll design that fills the entire panel in alto-relief and consists of a highly conventionalized acanthus, carved with great spirit.

103. In Figs. 42 and 43 are illustrated two of the clustered columns in the Cincinnati Chamber of Commerce, designed by the late H. H. Richardson. The capitals of these columns are Romanesque, and are beautiful in design and execution. As will be observed, the carving is not very deep; this is due to the fact that the stone, which is granite, is exceedingly hard.

104. The entrance to the Cable Building, New York City, designed by McKim, Meade, and White, shown in Fig. 44, is an example of stonework where sculpture, the sister art to stone carving, is used in connection with the conventionalized plant motifs, geometrical motifs, etc. already described and illustrated. The two draped figures in this example are quite close to the eye, and are therefore carved with considerable exactness and detail. It is probable that these figures were carved from scaffolds at the building, after plaster models of the figures had been previously approved by the architects.

FOUNDATIONS

Serial 5372 Edition 1

FOOTINGS

THEORY OF FOUNDATIONS

1. **Foundation and Foundation Bed.**—The term foundation, as used in connection with a building or other such structure, is commonly employed to designate both the lower portion of the structure and the soil on which the structure rests. However, the soil supporting the structure is sometimes called the foundation bed.

2. **Factors Governing Design of Foundations.**—In designing a building, the architect or engineer estimates the loads that must be supported by the foundation of the building and the weight of the foundation itself, and thereby determines the total load that will be transmitted by the foundation to the foundation bed. He also ascertains the load, per square foot of surface, that the soil can support safely. His problem is to design the foundation so that the pressure on any part of the soil will not be greater than the safe strength of the soil and also so as to avoid unequal settlement in the various parts of the building.

3. **Use of Footings.**—The weight of a building and its contents is carried by foundation walls and columns or piers. In the usual construction, these walls and columns rest on projecting courses called footings. A concrete footing for a concrete foundation wall is shown at *a* in Fig. 1. The purpose of a footing is to distribute the load from a wall *b* or a column over such an area of the foundation bed that the unit pressure on the soil will not exceed the load that can be safely supported by the soil.

4. Use of Piles.—Where a very soft and compressible soil extends to a great depth below the earth's surface, it may not be feasible to provide footings for the walls and columns, and to support the footings directly on the soil. Under such conditions, adequate support for the structure may be obtained by driving piles in the soil and resting the footings on these piles. A pile is a comparatively long, slender column of timber, concrete, or metal and concrete that is driven vertically into the soil. Piles either rest on firm material that is some distance below the surface of the ground or may remain suspended in the soft soil. Even when so suspended, piles will carry heavy loads without objectionable settlement.

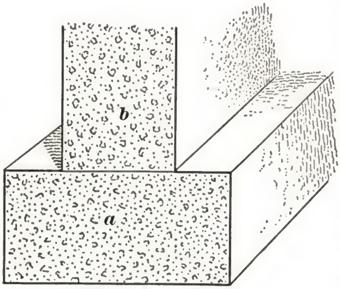


FIG. 1

5. Use of Caissons.—In some cases, a soft, compressible soil overlies a comparatively firm material which is at such a depth that it is advisable to excavate the softer material by the use of caissons and to rest the footings on the firm material. A caisson is a boxlike structure that is placed in the ground to prevent water and soft soil from flowing into the space to be occupied by a footing or other part of the building.

6. Required Data for Design of Foundations.—In order to design the foundation for a building, it is necessary to have the following data: The weights of the walls and columns; the loads that are expected to be transmitted to those supports from the floors and roof of the building; the probable weights of the footings; and the load that can be safely carried by each square foot of the soil on which the footings rest or, if piles are to be used, the load that can be safely supported by each pile. To obtain these data, it is necessary to have a knowledge of the weights of the materials that are used in the building, the loads that are likely to come on the floors and roof of the building, and the strength of the soil on which the building is to be supported.

7. Settlement.—When a building is placed on a foundation bed, the weight of the building tends to compress the soil and, as a result, the building tends to settle. A tall building frequently settles as much as 3 or 4 inches before coming to rest. Such settlement does no harm if the building settles equally in all parts. However, if a building settles more in one part than in another, the walls will crack and the floors will be thrown out of level. In some instances a portion of a building settled badly and it became necessary to provide new foundations under that portion in order to prevent further settlement. Such operations are very expensive and should be avoided by obtaining an exact knowledge of the conditions before the construction of the building is begun and by designing the foundations properly.

SAFE LOADS ON EARTH FOUNDATION BEDS

8. Classification of Materials.—The materials usually regarded as suitable for the foundation bed of a structure may be classified as rock, hardpan, gravel, sand, clay, loam, and mixtures of two or more of these substances.

9. Rock.—Rock may be defined as a large mass of stony matter, either bedded in the earth or resting on its surface. In its undisturbed geological position, rock is the best material for a foundation bed, and such a bed is always sought for important structures.

In many cases, the strata or deposits of solid rock have been broken up into masses of various sizes and forms, and the pieces moved from their original positions, by the action of water and ice. Masses of considerable size and consisting of pieces of angular shape lying near the rock from which they were broken, are commonly called loose rock. Loose rock should not be used as a foundation bed for an important building.

10. Hardpan.—The hard stratum of soil underlying the surface soil is known as hardpan or pan. This term is also applied to a dense mass consisting of a mixture of clay, sand, and gravel. Hardpan is generally considered a good foundation bed.

11. Sand and Gravel.—Sand is any mass or collection of fine particles of stone that are not strictly reduced to powder or dust. Gravel is composed of small stones or fragments of stone or very small pebbles larger than particles of sand. Sand and gravel are likely to undergo slight initial compaction when subjected to pressure, and proper allowance should be made for this fact in designing structures to rest on foundation beds of either of these materials. However, there is only slight movement of the separate particles on each other, even when the material is saturated with water. The most serious danger in the case of a sand or gravel foundation bed is erosion by flowing water, and great care must be taken to protect such a bed from contact with currents of water.

12. Clay.—Clay is the general name given to cohesive soils. Such soils are smooth to the touch, and absorb water greedily either when in contact with it or from the atmosphere. When dry, a clay bed can sustain fairly heavy foundation loads without excessive yielding, but as it absorbs water its plasticity increases so that a wet clay flows readily under pressure. Furthermore, it is difficult to drain water from clay. Therefore, a clay soil that is exposed to the weather or is likely to come in contact with water is not desirable as a foundation material. Also, when clay is used as a foundation bed, precautions should be taken to prevent water from penetrating it.

13. Loam.—The soil known as loam is a natural mixture of sand and clay. It generally contains some organic matter that is likely to decompose, and for this reason is not considered a good foundation bed for buildings over one story in height. Some building codes prohibit the use of a foundation bed of loam or any soil containing organic matter.

14. Other Soils.—Some soils are of semiliquid nature and are so compressible that they can support but little weight. The most common materials of this class are alluvium, quicksand, and peat.

Alluvium is composed of the finer earth, sand, gravel, and similar material that has been washed from its original position

and transported by rivers, floods, or other means and deposited on land that is not permanently submerged.

Quicksand is a fine granular soil that is temporarily supersaturated with water and that acts like a fluid when subjected to pressure. If the water is drained off, and the soil is compacted and kept reasonably dry, the material makes a fairly good foundation bed.

Peat is a brown soil of vegetable origin consisting of partly decomposed roots and fibers, more or less saturated with water. It is quite spongy near the surface, but gets more compact the deeper down it is excavated. However, as peat is subject to further decomposition, it is not a suitable material for a foundation bed.

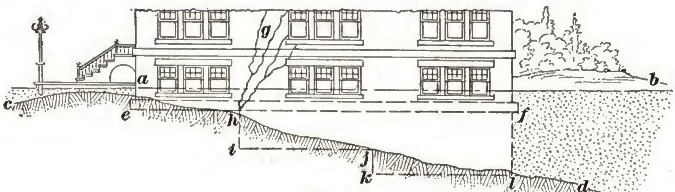


Fig. 2

15. Recommended Values of Safe Pressures on Foundation Beds.—Most cities specify in their building codes the maximum unit pressures that are allowable on foundation beds. In general, these codes are the results of careful investigation. However, as different soils are sometimes given the same name by various codes and as the unit pressures specified in those codes are often based on different sources of information, there is considerable variation in the provisions of these codes. According to the New York building code, the safe loads on foundation beds are as given in Table I.

16. It sometimes happens that the part of the foundation bed near the ground surface is composed of soils of different degrees of compressibility. In Fig. 2, for example, *ab* represents the natural surface of soft soil and *cd* represents the natural surface of comparatively firm material underlying it. If the bearing surface of the foundation bed under the footing

TABLE I

SAFE LOADS ON EARTH FOUNDATION BEDS

Class	Kind of Material	Loads in Tons per Square Foot
1	Hard sound rock	40
	Medium hard rock	25
2	Hardpan overlying rock	10
	Soft rock	8
	Gravel	6
3	Sand, firm and coarse	4
	Sand, fine and dry	3
4	Clay, hard and dry	3
	Clay, firm	2
	Sand and clay, mixed or in layers	2
	Sand, fine and wet (confined)	2
5	Clay, soft	1

for the wall of the building lies entirely in the horizontal plane *ef*, part of the footing rests on the firm material, while the remainder of the footing rests on the soft soil. Unless precautions are taken to prevent unequal settlement of the two parts of the footing, the wall is likely to crack as indicated at *gh*.

There are two possible methods for preventing unequal settlement. One method is to rest all parts of the footing on firm material by excavating it to the lines *ij* and *kl*. Another method is to make the part of the footing that rests on the soft soil wider than the part that rests on the firm material. If the second method is used, it is desirable to conform to the following stipulation in the New York building code: When footings for a building rest on foundation materials of different strengths, the safe load on the stronger material should be taken as the value given in Table I. If the weaker material is in the same class or in the next lower class, the safe load for that material may also be as given in Table I. If, however, the difference between the numbers of the classes in which the materials are ranked is more than 1, the safe load for the weaker material should be determined by reducing the value given in Table I by a per cent equal to 10 times that difference.

Example.—One part of a foundation bed is gravel and the other part is a mixture of sand and clay. What should be the safe loads on these materials?

Solution.—According to Table I, gravel is in class 2, and a mixture of sand and clay is in class 4. Also, the safe loads given in the table for these materials are, respectively, 6 and 2 tons per sq. ft. Since the difference between the class numbers is $4-2=2$, which is more than 1, the adopted safe load for the weaker material should be less than the tabulated value by $10\times 2=20$ per cent. Hence, the safe loads, in tons per sq. ft., should be 6 for the gravel and $2-(0.2\times 2)=1.6$ for the mixture of sand and clay. Ans.

17. Necessity for Investigation of Foundation Bed.—It is generally unsafe to trust to surface appearances in judging the character, strength, and soundness of foundation beds. A stratum of rock may, when its surface is uncovered, appear to be of satisfactory character, without serious fissures or other defects, and may give the impression of being continuous and solid to a great depth. This appearance may, however, be deceptive. As a matter of fact, the layer of rock may be comparatively thin, and may be underlaid with a body of soft clay or other unresisting material. Therefore, it may not be capable of sustaining a structure designed to rest on solid rock. The architect who is responsible for the design of an important structure usually engages a competent engineer to design the foundations. The engineer should make a careful investigation of the material that is to constitute the foundation bed, and he should satisfy himself that the conditions below the surface are not such as may ultimately result in the destruction or impairment of the proposed structure.

LOADS ON FOOTINGS

18. Classes of Loads.—The loads that are transferred by the footings of a structure to the foundation bed may be classified as dead load, live load, and wind load. The dead load includes the weight of the structure and all permanent fixtures in it. The live load includes such movable or varying loads as the weight of people, furniture, machinery, and stocks of goods. In the design of footings, the weight of snow that may accumulate on the roof is also considered as part of the live load. The

TABLE II

WEIGHTS OF BUILDING MATERIALS

Name of Material	Average Weight Pounds per Cubic Foot
Bluestone	160
Brickwork, in cement mortar (average)	130
Brickwork, in lime mortar (average)	120
Brickwork, pressed brick, thin joints	140
Concrete, cinder	112
Concrete, gravel	140
Concrete, slag	135
Concrete, Stone	145
Concrete, reinforced	150
Granite	165 to 177
Iron, cast	450
Iron, wrought	480
Limestone	155 to 172
Marble	171 to 179
Masonry, squared granite or limestone	165
Masonry, granite or limestone rubble	150
Masonry, granite or limestone dry rubble	138
Masonry, sandstone	150
Sandstone, building, dry	132 to 172
Slate	172 to 177
Steel, structural	489.6
Terra cotta, solid	120
Terra-cotta masonry work	70 to 80
Wood	40

wind load is that due to the pressure exerted by the wind when it blows against the structure.

19. Dead Load.—The weight of any part of a structure can be calculated by multiplying the volume of material in the part, in cubic feet, by the weight of a cubic foot of the material. In Table II are given the weights, in pounds per cubic foot, of common building materials. The weight of a cubic foot of wood depends on the species and the amount of moisture it contains, but an average weight of 40 pounds per cubic foot is often assumed for all species and degrees of dryness.

TABLE III

WEIGHTS OF FLOOR CONSTRUCTION

Type of Floor	Weight Pounds per Square Foot
Wood floors for dwellings, light construction	12 to 17
Wood floors for dwellings, heavy construction	14 to 20
Wood floors for mills	20
Concrete slabs with wood flooring	60 to 90
Terra-cotta arches with wood flooring	50 to 70

The weight of a floor, roof, or partition is generally determined best by first estimating the weight of a strip whose area is 1 square foot and whose thickness is the average thickness of the construction; and then multiplying that weight by the total area, in square feet. The approximate weights, in pounds per square foot, of a few types of floor construction are given in Table III.

20. Live Loads on Floors.—The live load that a floor system will be required to support is variable and uncertain, and it cannot be determined accurately in advance. In estimating the live load that will probably come on the floor, the main consideration is the use to which the building is to be put. A careful study is made of the conditions of loading to which the building will probably be subjected, and the maximum live load is assumed accordingly.

If the building is to be erected in a large city, the live load for which the floor system is designed must comply with the building laws of that city. The requirements are not the same for all cities, as shown by Table IV, in which are given the minimum live loads allowed for various types of buildings in six of the larger cities in the United States. The loads given in the second column, which is headed *Experiment,* are based on the results of tests made to determine the actual loads that come on floors in buildings of various types. These loads are much smaller than the loads specified by city building codes.

TABLE IV

MINIMUM LIVE LOADS ON FLOORS, IN POUNDS PER SQUARE FOOT OF SURFACE

Purpose of Building	Experiment	New York	Chicago	San Francisco	Boston	Indianapolis	Pittsburgh
Dwellings, Apartments	20 to 40	40	40	60	50	50	40
Hotels	20 to 40	40	40	60	50	50	70
Office Buildings ...	16 to 33	50	50	60	60	75	70
Churches	15 to 25	60	75			125	100
Ball rooms		100	100	125	100	125	150
Theatres	44	75	75	75		125	100
Schools	15 to 25	60	50	75	50 to 100	100 to 200	70
Hospitals		40	40 to 100	60	50	50	70
Factories		75 up	100		125 to 250	150	125
Stores	50 to 80	100 up	100	125 to 250	125 to 250	100 to 200	100
Warehouses		120 up	100		125 to 250	100 to 200	100 to 150
Sidewalks		300		150	250	300	
Roofs		40	25	20 to 30	40	30	40

21. Wind Load on Footings.—A strong wind blowing horizontally against one side of a tall building, as indicated in Fig. 3, tends to tip the building into the position represented by the dotted lines. Although the building is not moved perceptibly, the tendency for it to rotate causes a vertical pressure on the foundation bed under the wall *ab*. At the same time, the wall *cdfe* tends to rise and the pressure on the foundation bed under that wall is reduced. However, since the wind may blow in any direction and a reversal of direction would cause an increase in pressure on the foundation bed under the wall *cdfe*, all footings of a tall building must be made large enough to allow for the wind load.

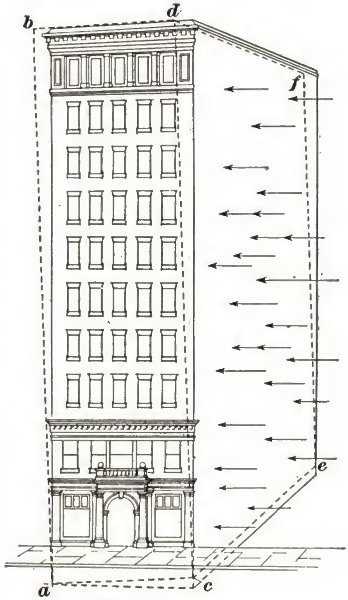


FIG. 3

The maximum horizontal pressure that can be exerted on a vertical wall by the wind is about 30 pounds per square foot. The building codes of different cities make different provisions for the wind load. It is customary to neglect the wind pressure on the walls of any building that is less than 100 feet high.

22. Reduced Live Loads on Footings.—It is improbable that every part of the roof and all the floors of a building will carry the full specified live load at the same time. Many building codes, therefore, stipulate that the footings may be designed for full dead loads and partial live loads on the floors. For example, the New York building code contains the following provisions:

In structures intended for storage purposes, all columns, piers or walls and foundations may be designed for eighty-five per cent of the full assumed live load. In structures intended for other uses, the

assumed live load used in designing all columns, piers or walls and foundations may be as follows: one hundred per cent of the live load on the roof, eighty-five per cent of the live load on the top floor, eighty per cent of the live load on the next floor, seventy-five per cent of the live load on the floor next below. On each successive lower floor there shall be a corresponding decrease in the percentage, provided that in all cases at least fifty per cent of the live load shall be assumed.

23. Total Loads on Wall Footings.—In calculating the required width of a footing under a wall, it is customary to consider the load carried by a linear foot of the wall. If a wall does not support any beams or joists and transmits only its own weight to the foundation bed, the load is entirely dead load and is generally uniformly distributed. In some buildings, floor loads are transmitted to the walls by joists or beams that are spaced relatively far apart. However, such concentrated loads are gradually distributed over the masonry below, and the load on the footing for the wall may usually be considered uniform. The load per linear foot of wall may then be calculated by taking the sum of the weight of a linear foot of wall and the floor and roof loads that come on a strip having a length of one foot and a width equal to half the distance from the wall to the nearest line of interior columns.

In performing the calculations for the design of footings, it is not practical to use too many significant figures. The assumed weights of the unit volumes of the building materials and the assumed floor loads are approximate values. It is, therefore, satisfactory for practical purposes to express the weights of the different parts of the building and the loads on such parts by numbers with not more than three or four significant figures, as is done in the following example.

Example.—In Fig. 4 (*a*), (*b*), (*c*) and (*d*) are shown diagrams giving dimensions for a building. The dead load per square foot is estimated to be 60 pounds for the roof and 75 pounds for each floor. The live load per square foot is specified as 40 pounds for the roof, 50 pounds for each upper floor, and 100 pounds for the first floor. If the weight of brickwork is taken as 130 pounds per cubic foot, what is the total load per linear foot on the footing under either side wall?

Solution.—The dimensions of the side walls are shown in Fig. 4 (*c*). Also, as indicated by the areas bounded by dotted lines in

view (a), the floor and roof loads are carried partly by the interior columns and partly by the walls and piers. The area that contributes load to an interior column is a rectangle like that marked a. This rectangle extends longitudinally 7 ft. on each side of the center line of

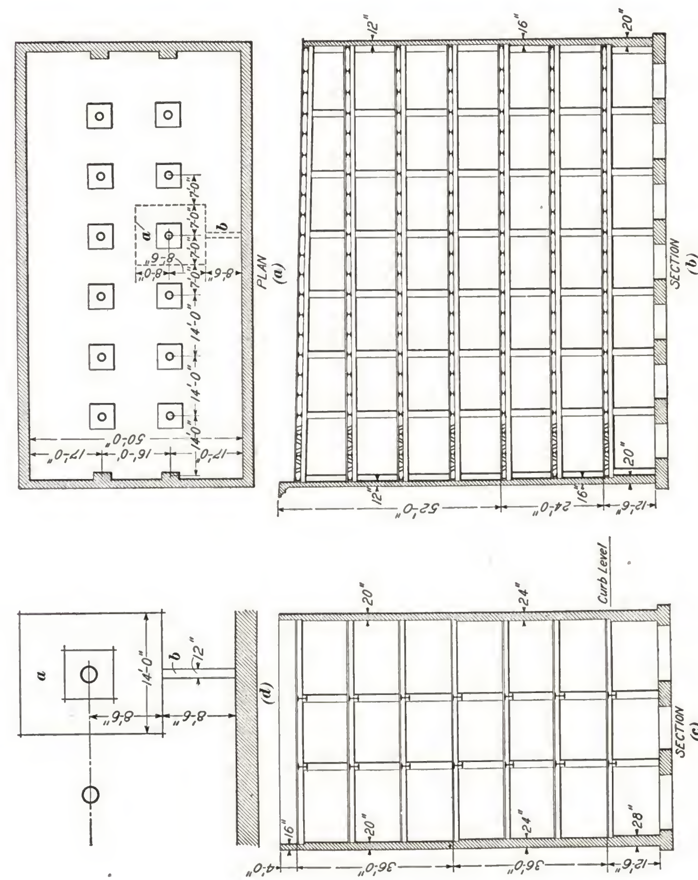


Fig. 4

the column, and it extends transversely 8 ft. 6 in. from the column center toward the wall and 8 ft. from the column center toward the other line of interior columns. The area that contributes load to a linear foot of wall is a rectangle, like that marked b, which has a length of 1 ft., or 12 in., and a width of 8 ft. 6 in. The rectangles a and b are shown to a larger scale in view (d).

In this example, each weight will be taken to the nearest 10 lb. For instance, although $4\times1\frac{1}{3}\times1\times130=693\frac{1}{3}$, the result is called 690. The dead loads may be tabulated in the following manner:

Weight of wall	$4\times1\frac{1}{3}\times1\times130=$	690 lb.
	$36\times1\frac{2}{3}\times1\times130=$	7,800
	$36\times2\times1\times130=$	9,360
	$12.5\times2\frac{1}{3}\times1\times130=$	3,790
Weight of roof	$1\times8.5\times60=$	510
Weight of six floors	$6\times1\times8.5\times75=$	3,830
Total dead load		=25,980 lb.

The live loads on the roof and floors are as follows:

Roof	$8.5\times40\times1.00=$	340 lb.
6th floor	$8.5\times50\times0.85=$	360
5th floor	$8.5\times50\times0.80=$	340
4th floor	$8.5\times50\times0.75=$	320
3rd floor	$8.5\times50\times0.70=$	300
2nd floor	$8.5\times50\times0.65=$	280
1st floor	$8.5\times100\times0.60=$	510
Total live load		=2,450 lb.

The total load on a linear foot of the wall footing is $25{,}980+2{,}450=28{,}430$ lb. Ans.

24. Total Loads on Column Footings.—The load on a column in a building comes partly from the column directly above and partly from the floor system that is supported by the column under consideration. The load from that floor system is equal to the product of a certain floor area and the load on each square foot of the floor.

EXAMPLE.—The weight of the interior columns in a vertical line in the building shown in Fig. 4 is estimated to be 10,000 pounds. What is the total load on the footing under an interior column?

SOLUTION.—As shown in Fig. 4 (*a*), the portion of each floor or the roof that contributes load to an interior column is the rectangular portion *a*, the area of which is $16.5\times14=231$ sq. ft. The dead load on the column footing may be determined as follows:

Weight of columns		10,000 lb.
Weight of roof	$231\times60=$	13,860
Weight of six floors	$6\times231\times75=$	103,950
Total dead load		127,810 lb.

The live loads that come on a line of columns from the roof and floors follow:

Roof	$231\times 40\times 1.00=$	9,240 lb.
6th floor	$231\times 50\times 0.85=$	9,820
5th floor	$231\times 50\times 0.80=$	9,240
4th floor	$231\times 50\times 0.75=$	8,660
3rd floor	$231\times 50\times 0.70=$	8,090
2nd floor	$231\times 50\times 0.65=$	7,510
1st floor	$231\times 100\times 0.60=$	13,860
Total live load		66,420 lb.

The total load on a column footing is $127,810+66,420=194,230$ lb. Ans.

25. Weight of Footing.—As the weight of a footing is a large per cent of the load on the foundation bed, this weight must be considered in determining the required bearing area of the footing. However, since the exact weight cannot be found until the footing has been designed, it is necessary first to assume the weight of the footing. The assumption is based on past experience with similar footings, loads, and soil conditions. For the usual designs it is found that the weight of the footing is from 5 to 20 per cent of the sum of the dead load and the maximum live load on the wall or column, the percentage depending on the type of footing, the total load, and the bearing capacity of the soil.

PROPORTIONING BEARING AREAS OF FOOTINGS

26. Variations in Loads on Footings.—In order that the settlement of all parts of a structure may be uniform at all times, each footing of the structure must receive the same proportion of the total load on the structure under all conditions of loading. Such an ideal distribution of the load can seldom, if ever, be attained in a structure that sustains variable live loads, but it should be approached as nearly as practical limitations will permit.

The dead load is always present and, therefore, is most effective in causing settlement. Furthermore, the actual amount of the dead load and its distribution among the various footings can be predetermined accurately. On the other hand, the

amounts of the live loads and wind loads are different at different times or in the various parts of the structure. Thus, any part of the floor or the roof of a building may at some time be required to sustain the full assumed live load, but it is hardly probable that the entire building will ever be fully loaded at one time. The pressure exerted by the wind against any side of a building is usually assumed to be a horizontal load of 20 to 30 pounds per square foot of the vertical projection of the side. It is also assumed that the wind blows in one direction at a time. Actually, the force exerted by the wind continually varies, and it acts with the assumed maximum intensity at rare intervals and for short periods of time.

27. Effect of Variation in Loads on Actual Soil Pressure. If each footing of a structure were proportioned for the full dead load and the entire assumed live load, the unit pressure on the foundation bed would not be the same under all footings for the usual condition of loading. The variation in the unit soil pressure under different footings may be illustrated by investigating the building shown in Fig. 4 and considered in the examples of Arts. 23 and 24. If the foundation bed is assumed to have a safe strength of 3 tons, or 6,000 pounds per square foot, and the footing areas were proportioned for dead load and full live load, the required width of the wall footing would be $28{,}430 \div 6{,}000 = 4.74$ feet and the required area of a column footing would be $194{,}230 \div 6{,}000 = 32.37$ square feet. When the building carries no live load, as is likely to happen, the soil pressure under the wall footing would be $\frac{25{,}980}{4.74 \times 1} = 5{,}480$ pounds per square foot, while the pressure under a column footing would be only $\frac{127{,}810}{32.37} = 3{,}950$ pounds per square foot. Similarly, when the actual live load carried by the building is any fraction of the full live load used in proportioning the footing areas, the unit soil pressure under the wall footing differs from the unit pressure under the column footings. This difference, however, decreases as the per cent of the full live load that is actually present increases.

28. Methods of Proportioning Bearing Areas of Footings. Since the dead load is most effective in causing settlement, some designers proportion the footings of a building so as to obtain a uniform unit pressure under all footings when the dead load alone is present. However, the more usual practice is to assume that the full dead load and one-third to one-half of the live load are effective in causing settlement. The procedure in proportioning the footing areas is then as follows:

The dead load and the maximum live load for each footing are first determined. The footing that has the largest ratio of live to dead load is then chosen as an index footing and its minimum bearing area is computed by dividing the sum of the dead load and the full live load on it by the allowable soil pressure. A reduced working unit pressure is then found by dividing the sum of the entire dead load and one-third to one-half of the live load on the index footing by the bearing area. Finally, the bearing area of any other footing is found by dividing the sum of the full dead load and the same fraction of the live load on that footing by the reduced working unit pressure.

In buildings in which all loads are carried to the foundation bed through columns or piers and the walls serve merely as inclosure walls, it is customary to classify the columns into three groups, namely, interior columns, corner columns, and intermediate exterior columns. If the roof and floor loads are carried to the foundation bed partly through the outside walls, it is necessary to consider the wall footings and the column footings.

EXAMPLE.—A building is so loaded that the footing of each corner column carries a dead load of 170,000 pounds, including the estimated weight of the footing itself, and a live load of 35,500 pounds; the footing of each intermediate exterior column carries a dead load of 220,000 pounds and a live load of 71,000 pounds; and the footing of each interior column carries a dead load of 200,000 pounds and a live load of 142,000 pounds. (*a*) What should be the minimum bearing area for each footing if the allowable pressure on the soil is 3 tons per square foot? (*b*) What are the required bearing areas if the footings are proportioned for uniform settlement under dead load and one-third of the live load?

Solution.—(*a*) The total load on each footing for a corner column is 170,000+35,500=205,500 lb., and the minimum bearing area is $\frac{205,500}{6,000}$ =34.3 sq. ft. Ans.

For the footing of each intermediate exterior column the total load is 220,000+71,000=291,000 lb., and the minimum bearing area is $\frac{291,000}{6,000}$ =48.5 sq. ft. Ans.

In the case of the footing of an interior column, the total load is 200,000+142,000=342,000 lb., and the minimum bearing area is $\frac{342,000}{6,000}$ =57 sq. ft. Ans.

(*b*) The ratio of live to dead load is $\frac{35,500}{170,000}=0.21$ for the footing of a corner column, $\frac{71,000}{220,000}=0.32$ for that of an intermediate exterior column, and $\frac{142,000}{200,000}=0.71$ for that of an interior column. As the ratio of live to dead load is largest for the footing of an interior column, that footing will be chosen as the index footing and the minimum bearing area of 57 sq. ft. will be retained for it. Ans.

The sum of the dead load and one-third of the live load on the footing of an interior column is $200,000+\frac{1}{3}\times 142,000=247,300$ lb., and the reduced working unit pressure is $\frac{247,300}{57}=4,340$ lb. per sq. ft. For the footing of an intermediate exterior column, the sum of the dead load and one-third of the live load is $220,000+\frac{1}{3}\times 71,000=243,700$ lb., and the required bearing area is $\frac{243,700}{4,340}=56.2$ sq. ft. Ans.

For the footing of a corner column, the sum of the dead load and one-third of the live load is $170,000+\frac{1}{3}\times 35,500=181,800$ lb., and the required bearing area is $\frac{181,800}{4,340}=41.9$ sq. ft. Ans.

PLAIN MASONRY FOOTINGS

29. Use of Plain Masonry Footings.—Footings of plain masonry are used mainly for walls and columns that carry light loads, such as the walls and columns in residences. Column footings for a tall building resting on a compressible soil are usually constructed of reinforced concrete and sometimes of steel beams encased in concrete. The wall footings for such a structure are generally of reinforced concrete. If plain masonry footings were used for a tall building that rests on a compressible soil, the footings would be of such great depth and volume as to make the cost of materials and excavation very high. Furthermore, their weight would add considerably to the already heavy loads transferred to the foundation soil from the columns. However, plain masonry footings may be used advantageously for walls and columns that carry heavy loads either when the soil has a high bearing capacity or when the conditions are such that footings of great depth and volume are not objectionable.

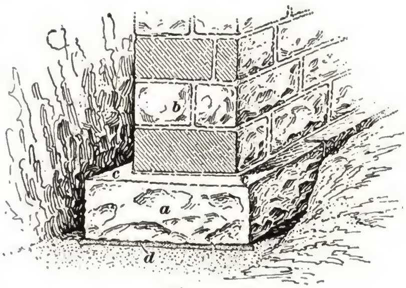


FIG. 5

Plain masonry footings are generally made of plain concrete. In former years, stone and brick footings were in common use; but, in modern construction, stone footings are used only occasionally and brick footings are hardly ever used, because it is much more advantageous to use plain concrete.

30. Stone Footings.—A simple type of stone footing for a wall is shown in Fig. 5. The footing *a* consists of large flat stones that are at least 12 inches wider than the wall *b*. The thickness of the stones should be sufficient to prevent the projecting parts *c* from breaking off. Each stone in the footing must be carefully bedded, or set on the foundation bed so as to bear on the soil at all points. A bed of mortar *d* is some-

times placed under the stones to insure an even bearing on the soil.

31. Types of Plain-Concrete Footings.—When the depth of a plain-concrete footing for a wall or column is not great, it may consist of a slab of uniform thickness. Such a footing for a wall is shown in Fig. 1. However, comparatively deep concrete footings are usually stepped in order to reduce the weight and cost of the concrete. A stepped footing for a column is shown in Fig. 6. The volume of concrete can also be reduced by sloping the sides of the footing, but stepping is usually preferred because it avoids the difficulty of holding the inclined forms in place during construction.

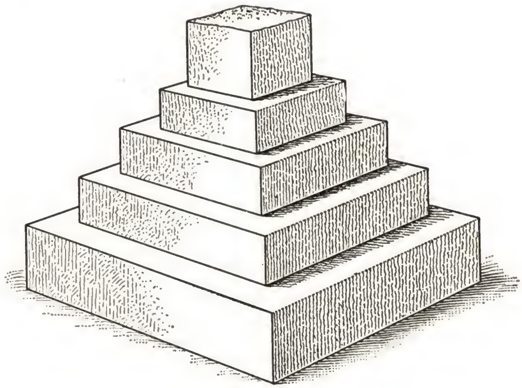


FIG. 6

32. Design of Column Footings of Plain Concrete.—The first operation in the design of a plain-concrete footing for a column is to assume the weight of the footing as a per cent of the total column load and to add it to the total dead load. The per cent that is to be assumed depends on prevailing conditions, being higher for the lower bearing capacities of the soil and lower for the greater column loads. For moderate loads and bearing capacities of 2 to 3 tons per square foot, the weight may be assumed to be 20 to 10 per cent of the total column load. After the weight is assumed, the next operation is to proportion the footing area. In the case of an interior footing,

the approximate bearing area is found by dividing the total load by the allowable bearing capacity of the soil. For an exterior footing, the area is found by dividing the sum of the dead load and a fraction of the live load by a reduced working unit pressure, as explained in Art. 27. Trial dimensions of the base are then selected to provide the required area.

When the dimensions of the base of the footing and the dimensions of the base of the column are known, the greatest projection of the footing beyond the column base is determined, and the depth of the footing is usually made equal to twice that projection. The number of steps into which the footing is to be divided and also the dimensions of each step can then be established arbitrarily. The height of a step should not be less than 12 inches. Also, the projection of each step beyond the part above it should not be greater than half the depth of the respective step. The actual weight of the footing should be computed. If this weight differs materially from the assumed weight, the footing is redesigned.

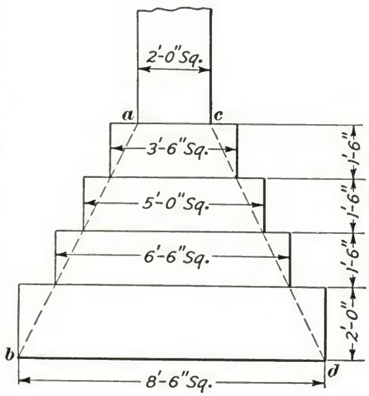


FIG. 7

EXAMPLE.—The base of an interior column carrying a central load of 300,000 pounds is 24 inches square. Design a plain-concrete footing to support the column on a soil whose safe bearing capacity is $2\frac{1}{2}$ tons per square foot.

SOLUTION.—If the weight of the footing is assumed to be 15 per cent of the column load or $0.15\times 300{,}000=45{,}000$ lb., the total load on the soil is $300{,}000+45{,}000=345{,}000$ lb. The corresponding footing area is $345{,}000\div 5{,}000=69$ sq. ft., and a footing 8 ft. 6 in. square will be tried.

The length of the projection of the footing beyond the edge of the column base is $\dfrac{8.5-2}{2}=3.25$ ft., and the required depth of the footing is $2\times 3.25=6.5$ ft. or 6 ft. 6 in. If the footing is designed as indicated in Fig. 7, its volume is $8.5^2\times 2+6.5^2\times 1.5+5^2\times 1.5+3.5^2\times 1.5=264$ cu. ft.;

and, if concrete is assumed to weigh 150 lb. per cu. ft., the actual weight of the footing is $264 \times 150 = 39{,}600$ lb. This is less than the assumed weight but the difference is not enough to require a new design. Hence, the dimensions previously established are adopted.

In Fig. 7, the height of each step is made equal to twice its projection. Hence, the inclined lines *ab* and *cd*, which join the edges of the column base to the edges of the footing base, also pass through the edges of the base of each step.

33. Design of Wall Footings.—The procedure in the design of a footing for a wall is essentially the same as for a column footing. It is usually convenient to consider a portion of the wall 1 foot long.

EXAMPLE.—A wall that is 30 inches thick carries a load of 24,000 pounds per linear foot, which is assumed to be centrally applied. Design a footing for the wall if the soil has a bearing capacity of 2 tons per square foot.

SOLUTION.—If the weight of the footing is taken as 15 per cent of the load, or $0.15 \times 24{,}000 = 3{,}600$ lb., the total load on the soil is 27,600 lb. per lin. ft. The required width of the footing is $27{,}600 \div 4{,}000 = 6.9$, or say 7 ft., and the projection on each side of the wall is $\frac{7-2.5}{2} = 2.25$ ft. Hence, the depth of the footing should be $2 \times 2.25 = 4.5$ ft. The footing will be made in three steps, each 1.5 ft. or 18 in. deep and projecting 9 in. beyond the course above.

The volume of the footing per lin. ft. is $7 \times 1.5 + 5.5 \times 1.5 + 4 \times 1.5 = 24.75$ cu. ft. and its weight is $24.75 \times 150 = 3{,}710$ lb. This is but slightly greater than the assumed weight and the trial design is adopted.

EXAMPLES FOR PRACTICE

1. A 20-inch square pier carries a central load of 180,000 pounds. It is to be supported by a plain-concrete footing whose width is limited by construction features to 5 ft. If the safe bearing capacity of the soil is 3 tons per square foot, what should be the length of the footing? Assume the weight of the footing to be 8 per cent of the column load. Ans. 6 ft. 6 in.

2. What should be the depth of the footing in the preceding example? Ans. 4 ft. 10 in.

3. If the footing in examples 1 and 2 is built in four steps of equal height and the projection in each direction is equally divided among the four steps, find the weight of the footing. Ans. 13,670 lb.

4. A 20-inch wall carrying a central load of 16,000 pounds per linear foot is to be supported by means of a plain-concrete footing on a soil

whose safe bearing capacity is 2 tons per square foot. Determine (*a*) the width of the footing and (*b*) its depth. The weight of the footing may be taken as 10 per cent of the load on the wall.

Ans. { (*a*) 4.4 ft., say 4 ft. 6 in.
(*b*) 2 ft. 10 in.

SPREAD FOOTINGS

34. Use of Spread Footings.—The term spread footing is applied to a footing that is shallow in depth and projects several feet beyond the column, pier, or wall resting on it. Spread footings are made of reinforced concrete or of grillages of steel beams encased in concrete. They are specially advantageous for the support of heavy loads where a relatively hard, but not deep, surface stratum is followed by a much softer stratum of great depth. The footings cannot then be economically carried to rock or hardpan and the driving of piles for their support is not advisable. Also, since the footings cannot be carried much below the surface, they could not very well be made of plain concrete because they would then have to extend into the basement and would occupy valuable space that might be used for engine rooms, shops, restaurants, etc. The designing of spread footings is the work of the engineer, but the architect should be familiar with the general features of construction of such footings.

35. Independent and Combined Column Footings.—A spread footing may be used to support one column or two or more columns. When a footing supports only one column, it is known as an independent column footing. Whenever conditions permit, such a footing is made square in plan. Sometimes, however, a square footing cannot be used because it would project beyond the building line or would be otherwise objectionable; and the footing is then made rectangular. If a footing is used to support two or more columns, it is known as a combined column footing. Combined footings are usually made rectangular.

36. Independent Reinforced-Concrete Column Footings. A reinforced-concrete spread footing for the support of a single column is usually made in one of three forms, namely, a slab

footing, a sloped footing, or a stepped footing. A slab footing, shown in plan and elevation, or side view, in Fig. 8, consists of a reinforced-concrete slab on which the column is supported; such a footing is advantageous for light column loads. For heavy loads, it is more economical to employ either a sloped footing, Fig. 9, in which the top of the footing slab slopes, or

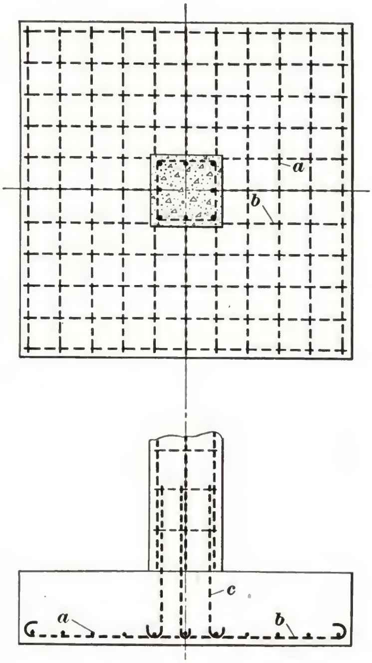


FIG. 8

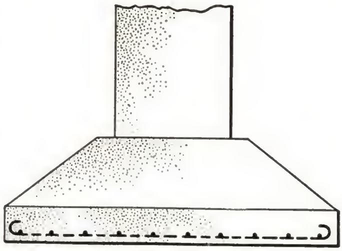


FIG. 9

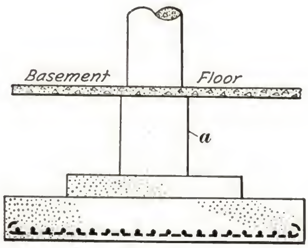


FIG. 10

a stepped footing, Fig. 10, which consists of a reinforced-concrete slab and one or more steps poured monolithically. The reinforcing rods are usually arranged in two layers, as *a* and *b* in Fig. 8, which are near the bottom of the footing. For the protection of the steel, at least 3 inches of concrete should be placed below the rods.

The compressive stress carried by the longitudinal rods in a reinforced-concrete column can be effectively transferred to the footing by means of dowels *c*, at least one dowel being pro-

vided for each rod in the column. It is often found advantageous to use a cap or short pier between the top of the footing and the base of the column in order to spread the load over a larger area of the footing. Also, where the footing is some distance below the basement floor, a plain-concrete pedestal, as *a* in Fig. 10, is usually introduced between the column and the footing.

37. Reinforced-Concrete Wall Footings.—Reinforced-concrete footings for walls may be of uniform thickness, stepped, or sloped. The main reinforcement consists of transverse rods placed near the bottom of the footing. Above them are placed longitudinal rods that serve to distribute the soil pressure to the transverse rods, to help the footing bridge over local soft spots in the foundation bed, and to keep the transverse rods properly spaced.

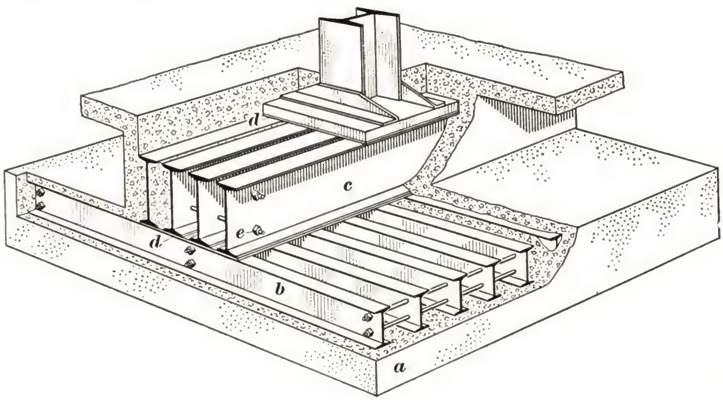


Fig. 11

38. Independent Grillage Footings.—A steel beam grillage footing for the support of one column is shown in perspective in Fig. 11. The same footing is also shown in Fig. 12 in plan in view (*a*) and in elevation in view (*b*). On the properly leveled foundation bed is laid a mat *a* of plain concrete. After this concrete has hardened sufficiently, the grillage beams *b* and *c* are placed upon it in layers or tiers, the beams of a tier being parallel to each other and at right angles to those of the next

tier. The outside dimensions of the mat are proportioned to give the required bearing area on the soil. The length that the concrete mat may safely project beyond the edges of the beams depends on the soil pressure. However, a projection of one-

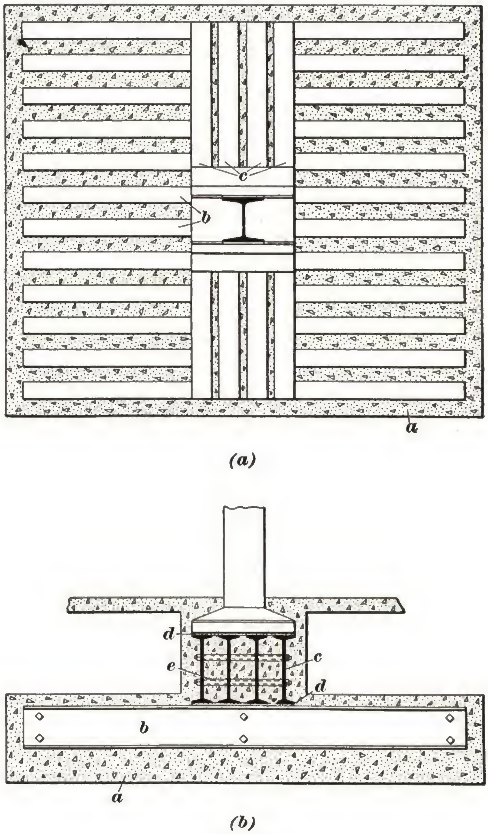


Fig. 12

half the thickness of the slab will be found permissible for the safe loads on earth foundation beds that are commonly used in the design of spread footings.

In order to protect the steel beams from corrosion, they should be covered by not less than 4 inches of concrete, and the spaces between them should be filled with concrete that is well

tamped. Provision for uniform bearing is sometimes made by setting the column base $\frac{3}{4}$ inch above the upper-tier beams and the beams of each tier $\frac{3}{4}$ inch above the tier below, and filling the $\frac{3}{4}$-inch spaces *d* with grout. For heavy column loads, it is customary to rest the base plate directly on the grillage beams and to place the beams of each tier directly on those of the tier below. The beams should then be carefully set so that their tops are at the same level and the base plate of the column should be true and flat.

In order that the beams of each tier may be kept the proper distance apart, they are secured to each other by means of $\frac{3}{4}$-inch bolts and separators, *e*, which are usually pieces of gas pipe and sometimes cast-iron plates provided with lugs. The separators should be placed not more than 6 inches from the ends of the beams and 5 to 6 feet apart. For beams that are 8 inches or less in depth, a single line of gas-pipe separators placed midway between flanges is sufficient; for deeper beams, such separators should be placed in pairs in a vertical line, as shown in Fig. 12 (*b*).

39. Combined Footings.—In providing grillage footings for columns, it is sometimes found necessary to rest two or more columns on one continuous footing. Most tall and heavy buildings are erected in large cities where the sites are very expensive and where the building cannot encroach upon adjacent property. The footings in such cases must be kept strictly within the boundaries of the lot. If an exterior column is so near the building line that a symmetrical footing cannot be provided for that column, it is usually best to support the exterior and the nearest interior columns on one continuous footing. A single footing for two columns would also become necessary when the columns are so placed that their separate footings would touch or overlap.

A combined footing of reinforced concrete for the support of two or more columns is usually a slab of uniform thickness that is rectangular in plan. A reinforced-concrete footing for the support of an exterior and an interior column is shown in Fig. 13, in plan in view (*a*), in elevation in (*b*), and in cross-

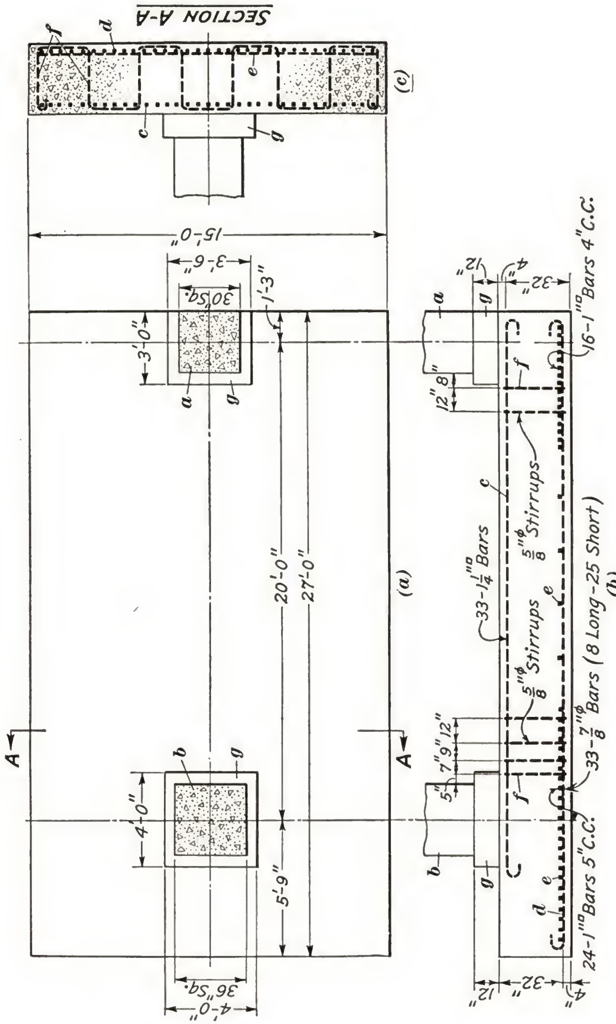


FIG. 13

section in (*c*). One edge of the footing is flush with the face of the exterior column *a*, which is on the building line, and the footing projects beyond the interior column *b*.

Between the columns, the main reinforcement consists of bars *c*, which are placed near the top of the footing. In the

projection beyond the interior column, the bars *d* are placed near the lower surface. A few of these bars are carried for the entire length of the footing and the others extend only a few feet beyond the interior column. It is also necessary to

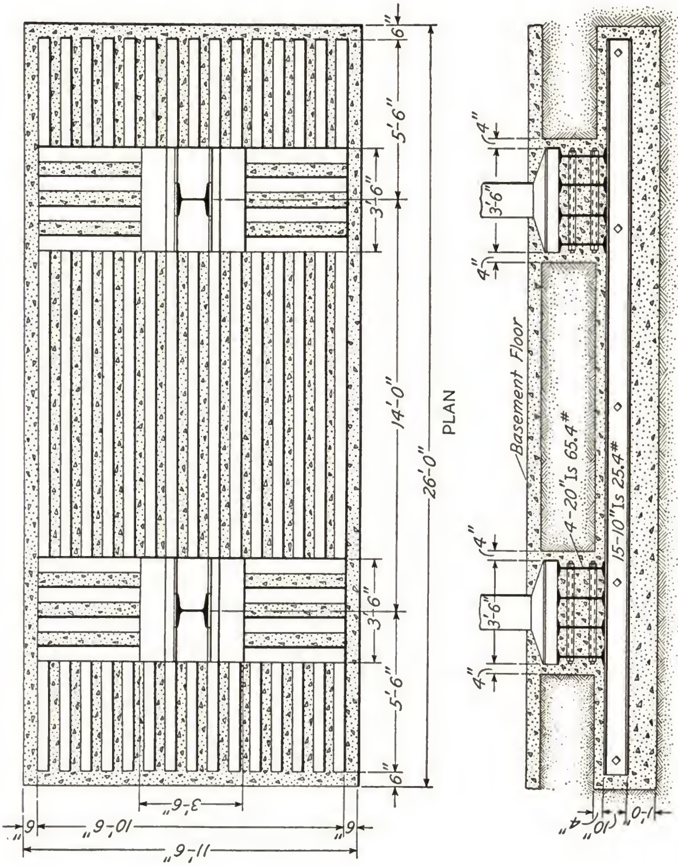
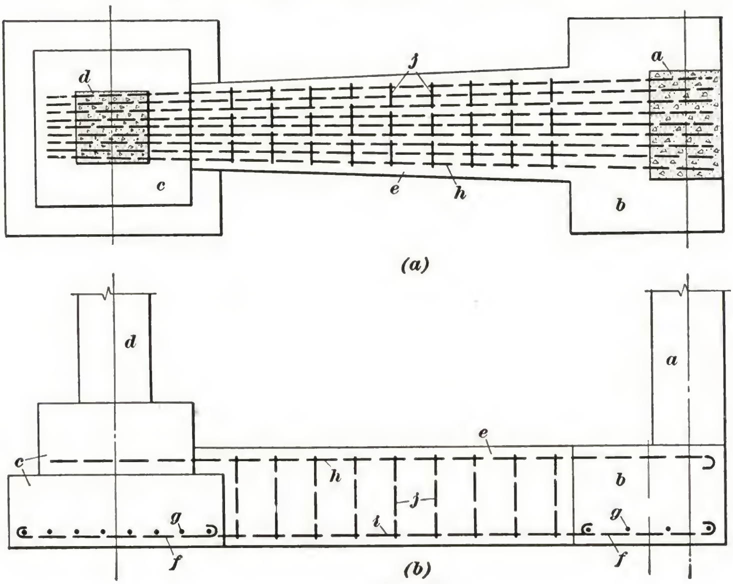


Fig. 14

reinforce the footing in a transverse direction by means of the bars *e*, which are laid near the bottom. As shown in view (*b*), these bars are usually placed closer together near the columns than near the middle of the length, but they are sometimes spaced uniformly for the entire length of the footing. Web

reinforcement is generally provided between the columns by stirrups *f*. Caps or pedestals *g* are often used to distribute the column loads over a larger area of the upper surface of the footing.

The numbers and sizes of bars called for in Fig. 13 apply to a particular footing, and the same amount of reinforcement would not be provided in every case. The notation 1″□ bars



(b)

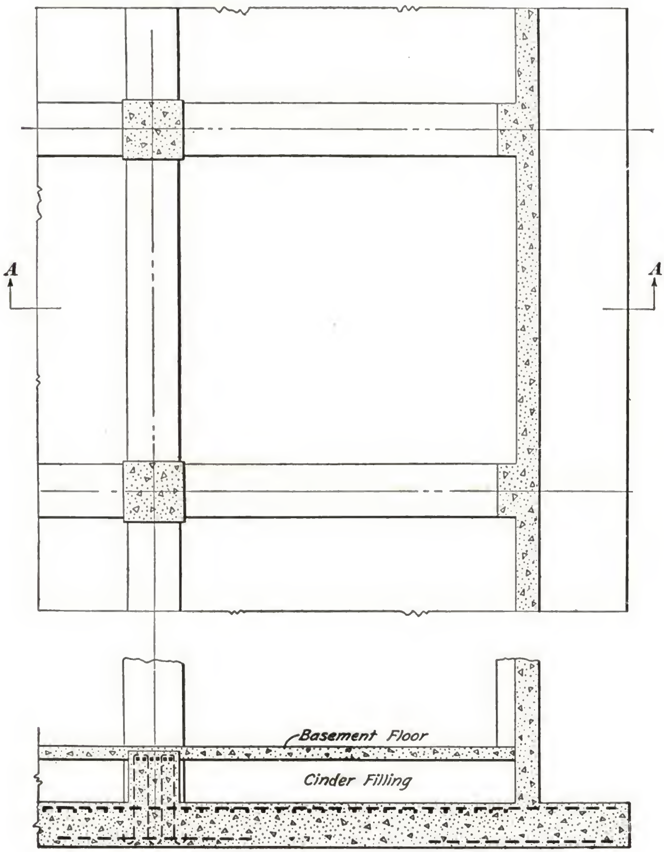
FIG. 15

means bars that are 1 inch square in cross-section, and the notation $\frac{5}{8}''$ ϕ stirrups means that the stirrups are made of round rods having a diameter of $\frac{5}{8}$ inch.

The arrangement of the beams in a combined grillage footing designed for the support of two equally-loaded columns is shown in Fig. 14, in plan and elevation.

40. Cantilever Footings.—Instead of a combined footing, a cantilever footing is sometimes used. A footing of this type is shown in Fig. 15, in plan in view (*a*) and in elevation in view (*b*). The exterior column *a* is supported on a footing *b*, which is symmetrical about the column in one direction but not

in the other. This column, being placed on the edge of the footing, tends to overturn it. To prevent the overturning, the footing for the exterior column is connected to the footing *c* of the nearest interior column *d* by means of a reinforced-concrete



Section A-A
FIG. 16

beam *e*, called a strap, or pump handle. The footings *b* and *c* are reinforced with rods *f* and *g* placed near the bottom and extending in both directions, in the same way as in independent footings.

Tensile stresses occur in the upper part of the strap beam and, hence, the main reinforcing bars *h* are placed near the top surface. Also, it is advisable to place a few bars *i* near the bottom of the strap beam, because the beam must be rigidly connected to the footing *c* and tensile stresses are produced in the lower part of the beam at the footing. Stirrups *j* are provided in the strap to help resist the diagonal-tension stresses; these stirrups are spaced uniformly between the footings *b* and *c*.

41. Mat Footing.—Where the bearing capacity of the soil is small and the use of piles is inadvisable, it may be necessary, in order to obtain the required bearing area on the foundation bed, to construct a footing in the form of a continuous concrete mat or raft, which covers the entire building site. By this means the weight of the whole building is distributed uniformly over the greatest possible area. The mat is usually reinforced with steel bars, and is constructed like an inverted floor. A mat footing with beams above the mat is shown in Fig. 16. The space between the mat and the basement floor is filled with cinders.

PREPARATION OF FOUNDATION BEDS

PRELIMINARY EXPLANATIONS

42. Depth of Foundation Bed.—The depth below the ground surface to which the foundation of a building is to be carried depends on the type and size of the structure, the character of the ground at the site, and the depth to which frost penetrates. In some cases, a satisfactory foundation bed is obtainable at or near the ground surface. Where it is advisable to support the structure on a foundation bed of firm material that is at a comparatively great depth, the softer overlying soil may be excavated by the use of caissons, and the footings may be constructed on the firm material; or else piles may be driven through the soft overlying material so as to rest on the firm material. In case firm material cannot be reached at a reasonable depth, the structure may be supported on piles that are suspended in the soft soil.

Foundations in earth should always be carried to such a depth below the ground surface that frost will not affect the underlying bed. Nearly all moist earth expands or heaves when the water freezes, and repeated freezing and thawing is likely to soften and disintegrate the foundation bed. The penetration of frost varies with the latitude. In the American Gulf States, ice seldom forms; while in the Great Lakes region, the ground sometimes freezes to a depth of 5 or even 6 feet. Ordinarily, in the northern parts of the United States, foundations 4 feet below the ground surface may be considered safe from injury by frost.

43. Dry and Wet Foundations.—Before the foundations of a structure can be built, the original ground must be removed to the proper depth. Where the excavation is shallow, the work can usually be carried on without much difficulty. But, where the foundation bed is at a great depth, and especially where the site is under water, the preparation of the foundation bed requires special construction. Hence, foundation beds may be classified as dry and wet, according to the nature of the problems to be solved in excavating the site and constructing the foundations.

44. Sheet Piling.—In both wet and dry excavations it is necessary to prevent the banks of the adjoining land from caving into the excavation. Quite often, especially in shallow excavations, the banks can be sloped back to stand at the natural angle of repose, or the inclination at which earth will rest without sliding. Where this is impossible, because the land is already occupied, or impractical, because of the large quantity of earth thereby added to the excavation, it becomes necessary to brace the banks. This is conveniently and efficiently done by means of sheet piling, as shown in Fig. 17. The piles *a* are driven side by side to form a wall around the excavation, and are braced against the pressure of the earth by the horizontal timbers *b* called wales and the horizontal or inclined pieces *c* called struts.

DRY FOUNDATION BEDS

45. Rock Foundation Bed.—The preparation of a shallow and dry foundation bed is generally a simple matter. In rock, it is usually necessary merely to excavate far enough below the

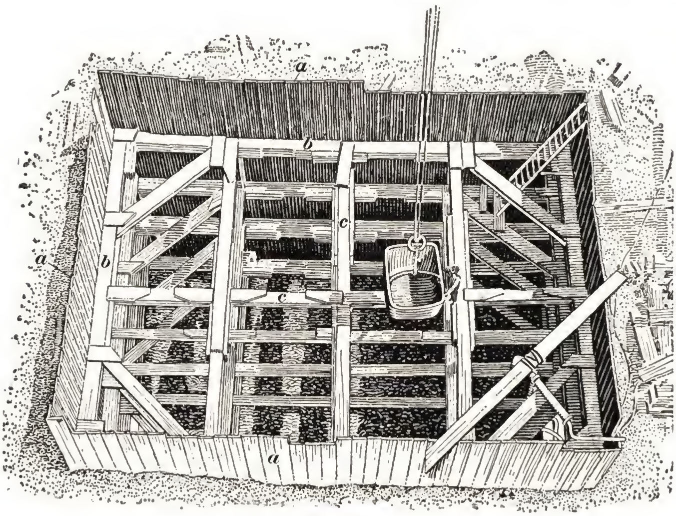


Fig. 17

surface to remove disintegrated and weather-worn rock, and to bring the surface into proper shape to receive the footings. The bed should not have a steep slope, and depressions in the rock should be filled with concrete. If, in Fig. 18, the

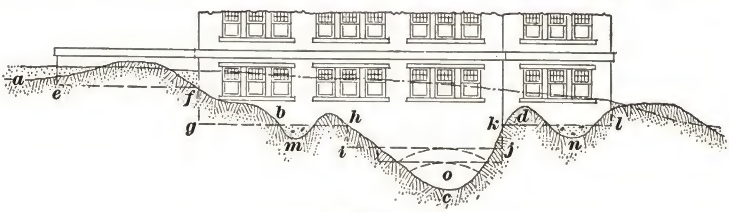


Fig. 18

line *abcd* represents the natural rock surface, rock would be excavated and concrete would be deposited so that the footings would bear on the horizontal surfaces *ef, gh, ij,* and *kl.* The

small cavities at m and n could be completely filled with concrete. The larger hollow at o could be left partly filled with earth, and firm support for the footings could be provided by a reinforced-concrete beam or an arch that transmits the load to the rock. All bearing areas need not be absolutely horizontal. If a surface is slightly inclined, however, it should be left rough in order to reduce the tendency for the footing to slide.

46. Earth Foundation Bed.—In the preparation of earth foundation beds, the material is excavated to a sufficient depth, sheet piling being used if necessary, and the whole area is graded. In very soft and compressible material, measures are sometimes taken to solidify or reinforce the foundation bed before the structure is begun. One method is to compress the soil into a more compact mass by driving a large number of short wooden piles over the area. Unless these piles are below the permanent ground-water level, they are likely to decay in a short time and become useless. Hence, in a soil that is above the ground-water level, piles are sometimes driven and at once pulled out, and the holes are filled with clean sand or gravel.

WET FOUNDATION BEDS

47. Methods Used.—The chief and most common obstacle in foundation work is water, which is sometimes encountered in shallow foundations and almost always in deep foundations. Where the foundation of a structure must be placed in water, one of two methods is generally followed: (1) the *cofferdam method* in which the space to be occupied by the foundation is freed of water and the work proceeds as in dry material; (2) the *caisson method,* in which a box-like structure is employed for sinking the foundation through the water.

48. Cofferdam Method.—A cofferdam is a temporary water-tight structure enclosing an area from which the water may be removed, leaving a comparatively dry and protected space in which a foundation may be constructed as on dry land. A great variety of cofferdams have been used. The simplest

and most primitive cofferdam, which is suitable in very shallow water, is a bank of earth, clay, or sand rising above the water. Next in order is a simple timber structure surrounded by a bank of earth. After the cofferdam has been completed, the water is pumped out of the enclosed space.

Absolute water-tightness in a cofferdam is seldom required, as it is more economical to pump a little water that may seep into the enclosure than to build a structure that will not leak. However, the cofferdam itself should be fairly tight and water should be prevented from entering from the foundation bed in large quantities. If the material of the bed is pervious, the piling should be driven to an impervious stratum or else the surface of the bed should be sealed by placing a layer of concrete inside the cofferdam and allowing it to harden before pumping is begun.

49. Caissons.—Caissons may be divided into three classes: (1) the *box caisson,* which is a box with sides and bottom, but without a top; (2) the *open caisson,* or *dredging caisson,* which is usually a box having neither top nor bottom, but sometimes containing compartments that have bottoms; (3) the *pneumatic caisson,* which is a box with a top and no bottom, the name being derived from the fact that compressed air is used to keep the water out of the caisson. A caisson of any type is left in place to form a permanent part of the foundation.

Box caissons are rarely used in the construction of foundations for buildings. Open, or dredging, caissons are often used for heavy building foundations. A caisson for such work usually consists merely of an open cylinder of metal or masonry. After the caisson is put in position on the ground, excavation is carried on by dredging out the material through the cylinder. The caisson sinks as the excavation proceeds.

50. Pneumatic Caissons.—Pneumatic caissons are often used in excavations through wet ground for very heavy foundations. Caissons of moderate size may be of steel, but large caissons are usually built of wood or reinforced concrete. The essential features of a pneumatic caisson are illustrated diagram-

matically in Fig. 19. The men work in the working chamber *a*, which is closed on the sides and top but is open at the bottom so as to permit the excavation of the soil *b* beneath the caisson. Compressed air is fed into this chamber through pipes, such as *c*, in order to drive all water from the space in which the men work and from the material that is excavated. The men thus work in a dry chamber and the excavated material is comparatively dry and easy to handle.

As the excavation proceeds, the caisson sinks. The sinking is facilitated by providing a cutting edge *d* at the bottom of the caisson wall. Men and materials enter and leave the working chamber *a* through the shaft *e*, the base of which is securely fastened to the roof *f* of the working chamber. The excavated material is shoveled into the bucket *g* by the workmen and the bucket is hoisted to the surface.

At the top of the shaft *e* is an air lock, which serves two important functions. Air does not escape from the working chamber *a* when men or materials enter or leave the chamber. Also, a man does not have to pass suddenly from one pressure to another. A person suffers serious injury when he passes too quickly from the working chamber to the outside air or from the outside to the working chamber. The air lock consists of a chamber *h* provided with doors *i* and *j* that are fitted to close air-tight. If a man wishes to descend into the working chamber, he first passes through the door *i* into the chamber *h* with the door *j* closed and the pressure in the chamber *h* the same as that of the outside air. The upper door *i* is then shut and compressed air is slowly fed into the chamber *h* through valves until the pressure in it becomes equal to that in the working chamber *a*. When this condition is attained, the lower door *j* is opened and the man continues his descent by means of the ladder *k*. In the case of a man leaving the working chamber, the operations are reversed. With the pressure in the chamber *h* the same as that in the working chamber *a* and the door *i* closed, the man enters the chamber *h* through the door *j*. This door is then shut and the pressure in the chamber *h* is allowed to drop very gradually until atmospheric pressure is obtained, when the door *i* can be

opened and the man can leave the chamber *h*. The bucket *g* is passed through the air lock in a similar manner.

51. A crib or cofferdam *l*, Fig. 19, of steel, concrete, or timber is built on top of the working chamber and sinks with it. When the caisson reaches the surface of the rock *m*, the working

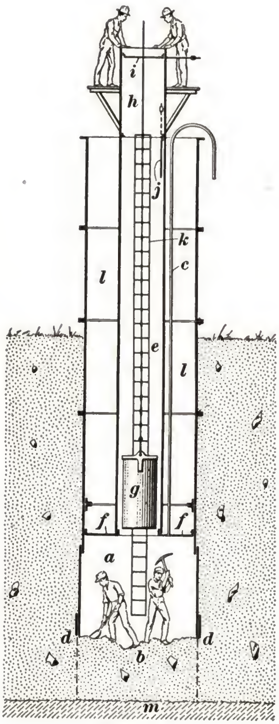


FIG. 19

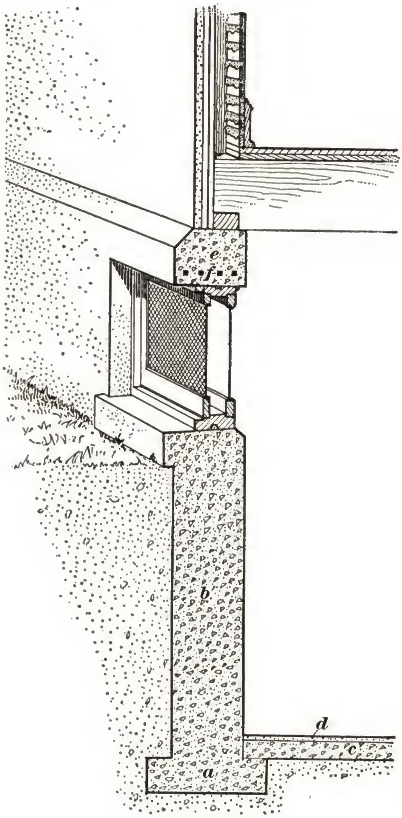


FIG. 20

chamber is filled with concrete. Since this concrete and the cofferdam prevent water from entering the caisson, air pressure is no longer necessary and the shaft and the air lock may be removed. The space inside the cofferdam is then filled with concrete to form a solid pier for the support of the building.

FOUNDATION WALLS

FEATURES OF CONSTRUCTION OF WALLS

52. Types of Walls.—Most buildings are constructed with basements and the walls are extended below the ground level. In some cases, the basement wall is in contact with the ground and in line with the outside wall of the building, as shown in Fig. 20. However, in the business districts of large cities, where land is valuable, the basement of a building is frequently extended beyond the building line so as to utilize the space beneath the sidewalk, as shown in Fig. 21. This extra space is called a vault, and its exterior wall is known as a vault wall. Sometimes, the space outside of a basement wall is left open, as shown in Fig. 22, either for admitting sunlight and fresh air to the basement or for providing access to the basement, or for both these purposes. Such a sunken space is called an area, and the exterior wall for it is known as an area wall. Basement walls, vault walls, and area walls are usually built of concrete, but stone, brick, and hollow terra cotta are also used.

53. Concrete Foundation Walls.—Part of the foundation wall in Fig. 20 extends above the ground surface, and light and air can be admitted to the basement of the building through windows that are located just above the ground. In the construction here shown, the footing *a* and the wall *b* are of plain concrete. The basement floor *c* in this case is also of plain concrete and is provided with a wearing surface *d*. Over each window is placed a concrete lintel *e* which is reinforced with steel bars *f*.

The vault shown in Fig. 21 is separated from the basement only by the piers *a*, which support the upper portions of the building. The concrete vault wall *b* is at the curb; the roof *c* of the vault also serves as the sidewalk; and the vault floor *d*

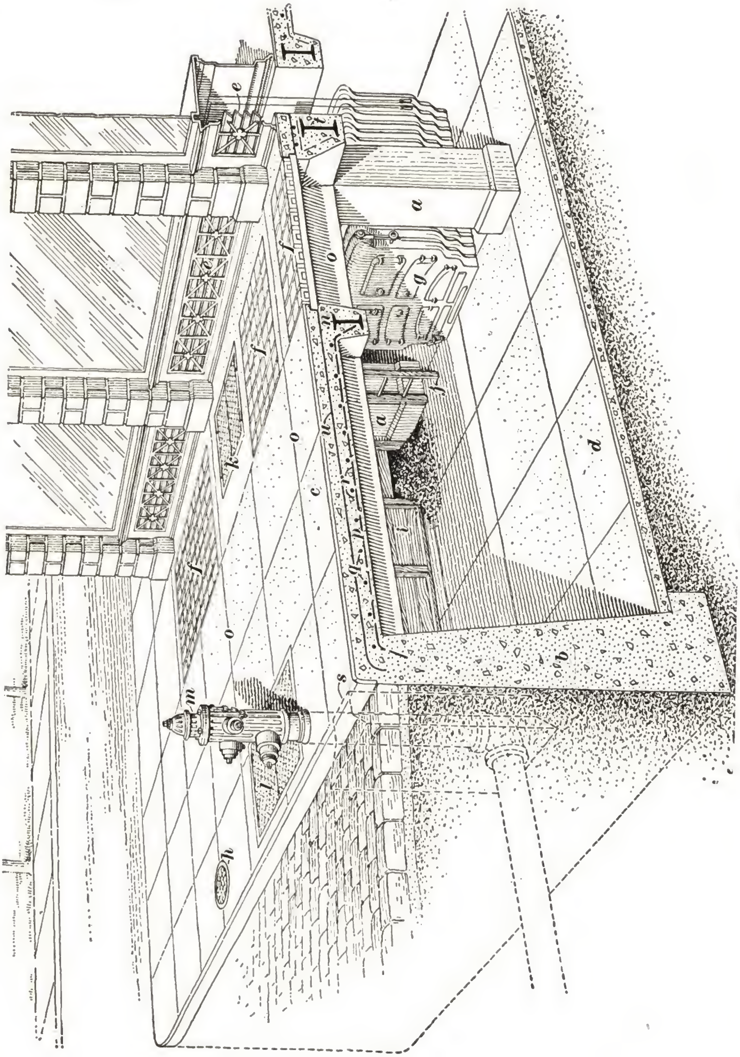
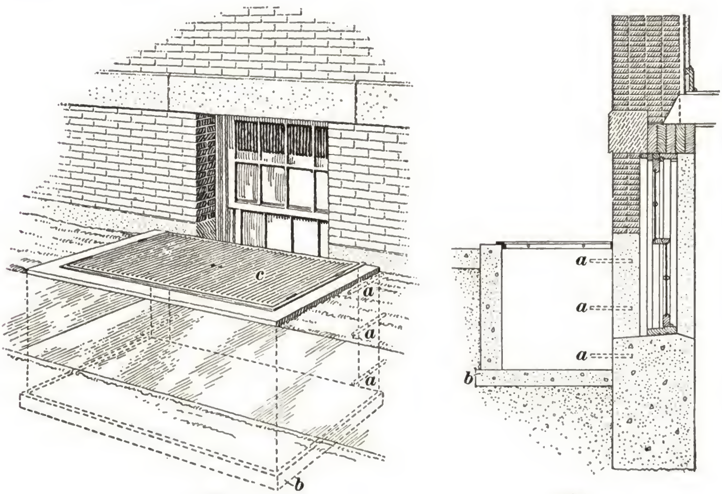


Fig. 21

is an extension of the basement floor. The footing of the vault wall in this case projects on only one side.

The area shown in Fig. 22 (*a*) and (*b*), is enclosed by thin concrete walls. These area walls are sometimes cast monolithically with the basement wall of the building. If they are cast separately, those at the ends of the area may be tied to the basement wall by steel bars *a* which are embedded in both the area walls and the basement wall. In this case, the floor *b* of the area serves as a footing for each area wall. The area is covered by the metal grating *c*.



(a) (b)

Fig. 22

The foundation and area walls shown in Figs. 20, 21, and 22 are of plain concrete, but foundation walls are often constructed of reinforced concrete. The arrangement of the reinforcement depends on the nature of the loads to which the wall is subjected.

54. Stone Foundation Walls.—Foundation walls are sometimes made of stone masonry in localities where stone is abundant and is easily quarried. When a stone foundation wall is concealed from outside view, as when it is in contact with the

ground, it is usually constructed of rubble masonry. However, the stones should be well bonded together and the joints and spaces should be filled with portland-cement mortar.

55. Brick and Terra-Cotta Foundation Walls.—Brick is occasionally used for foundation walls, but brickwork is usually too expensive for this purpose. Also, when a brick wall is used in wet soil, it absorbs enough water to cause dampness in the basement of the building.

In small residences, basement walls of hollow terra-cotta tiles are sometimes economical. However, many building codes do not permit the use of hollow blocks for the parts of foundation walls that are below the ground level and enclose basements.

56. Thickness of Foundation Walls.—In most cities, the minimum permissible thicknesses of foundation walls for buildings of various types are specified by the building code. The foundation walls of any structure should be thick enough to withstand the loads that may come on them.

OPENINGS IN WALLS

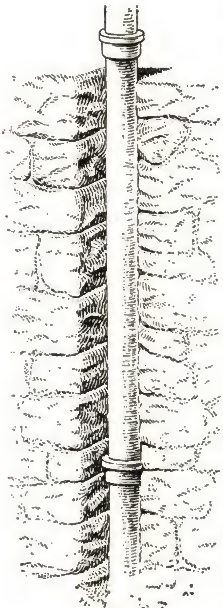
57. Various pipes, such as those for plumbing, water, and gas, pass through the foundation walls of buildings. In order that such pipes will not be crushed or broken in case of settlement of the walls, adequate provision for their protection should be made in the construction of the walls.

The opening for any pipe should be made somewhat larger than the pipe, and the top of the opening should be about 2 or 3 inches above the top of the pipe. The wall can then settle without putting any load on the pipe. Also, in order to reduce the cost of construction, the openings for the pipes should be left in the wall while it is being built, as cutting a hole through a masonry wall is a comparatively difficult operation.

Where water is likely to enter the building through the space between a pipe and the opening, this space should be filled with a soft composition such as asphalt or tar mixed with

either sand or paraffin. The water will then be excluded, but settlement of the wall will not injure the pipe.

58. Pipes that run vertically through a wall should be set in recesses, called *chases*. A pipe chase in a stone wall is shown in Fig. 23. Vertical chases may also be necessary to provide space for a stairway, chimney, or other purpose. In the plan in Fig. 24 is shown a foundation wall with a chase to accommodate a flight of stairs leading to the basement. If possible, a chase should be provided while the wall is being built, rather than by building a solid wall and cutting a channel in it.


(a)
Fig. 23

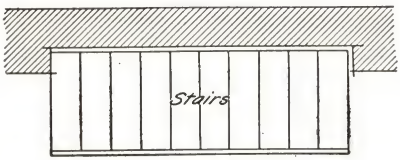


Fig. 24

59. Comparatively small horizontal openings in a masonry wall do not weaken the wall appreciably, as it may be assumed that the loads on the wall pass around such openings. In the case of a large opening, like a door or a window, it is customary to support the loads over the opening by means of a beam called a lintel.

WATERPROOFING OF FOUNDATIONS

60. Causes of Dampness in Cellars.—Where the cellar floor of a building is below the level to which ground water normally stands in the surrounding soil, water tends to seep through the cellar floor and walls into the building. Under some conditions, even where the ground-water level normally is below the cellar floor, water is soaked up by the soil and by the masonry in the wall by *capillary attraction*, and this water tends

to enter the cellar. Capillary attraction is the term used to describe the attraction that porous materials have for liquids. For example, if one edge of a piece of blotting paper is dipped in ink, the ink immediately rises in the blotter.

61. **Drainage.**—It is sometimes possible to keep a cellar fairly dry by draining the water from the soil around the building. The water may be carried to a sewer or cesspool by means of drains of porous terra-cotta pipe which are laid in a trench around the foundation walls. The joints between the lengths of pipe should not be filled with cement, as it is desirable to allow the water to enter the drains through the joints. However, in order to keep out particles of soil, the upper half of each joint should be covered with a piece of tarred paper or a small segment of pipe. The trench is filled with granular material like gravel, broken stone, or coarse sand, in order that the water will flow to the drains readily. If necessary, similar drains may be laid under the cellar floor.

62. **Use of Waterproofing Methods.**—Sandy or gravelly soils drain readily, and, unless the water stands at a high level in the soil because of the proximity of a river or lake, cellars built in such soils are seldom damp. Some clayey soils, however, tend to retain moisture and to allow water to rise above its normal level by capillary attraction. As a result, there is a tendency for cellars built in such soils to be damp. In order to keep water from seeping into a cellar where drainage is not effective, the cellar floor and walls must be made waterproof. There are four general methods of waterproofing the floors and walls of buildings. These methods are known as the integral method, the plaster-coat method, the iron method, and the membrane method.

63. **Integral Method.**—The so-called integral method of waterproofing can be applied only in case of concrete. This method is carried out by adding a waterproofing compound to the concrete while it is being mixed. The waterproofing compounds that are in use are in the form of liquids, powders, or pastes. They are used either for the purpose of helping to

fill the voids in the concrete or for producing a water-repellent condition within those voids. An effective compound for integral waterproofing is one that produces a permanent water-repellent condition within the voids and does not in any way weaken the concrete. These requirements are well met by the compounds known as ammonium stearate, calcium stearate, and aluminum stearate.

In using an integral waterproofing compound, it is highly important to follow carefully the directions of the manufacturer, as good results cannot be otherwise obtained. Also, where such compounds are employed, great care should be

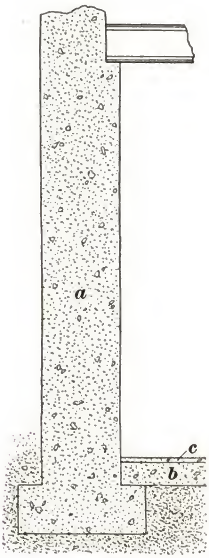


FIG. 25

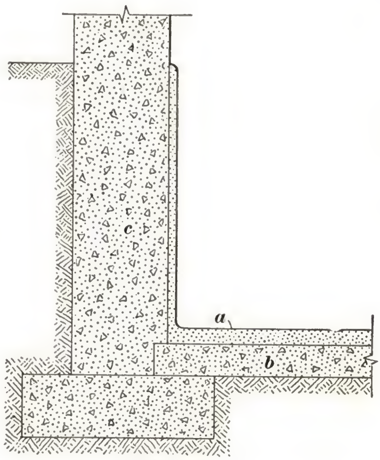


FIG. 26

taken to place the concrete so as to avoid openings for seepage. The construction joints occurring at the end of a pour should receive special attention, because any cracks in the slab or walls that permit seepage defeat the purpose of the waterproofing.

An example of a floor and cellar wall built according to the integral method is shown in Fig. 25. A wall is shown in sec-

tion at *a*. This wall is waterproof in itself and consequently needs no coatings. The same is true of the floor *b*. A wearing surface *c* of cement mortar is placed on top of the waterproofed concrete *b*.

64. Plaster-Coat Method.—The plaster-coat method of waterproofing consists in applying a waterproof plaster coat about $\frac{3}{4}$ inch thick to the inside surfaces of the basement walls and to the faces of the columns, and a coat about 2 inches thick to the upper surface of the floor slab. The basement walls and columns are coated up to the level of the ground water. As shown in Fig. 26, a mortar coat *a* is applied on the inside of the floor slab *b* and the basement wall *c*. Special attention should be given to the joint between the floor and the walls. The walls are waterproofed first, and the mortar coat is stopped about 6 inches above the floor. The floor coat is then laid, being carried up the wall and rounded along a neat line where it meets the thinner wall coating. In the case of a floor that is subject to water pressure from below, as where the floor is below the ground-water level, the floor slab *b* is usually keyed into the wall *c* to resist uplift.

65. Iron Waterproofing.—Several manufacturers produce a penetrating waterproofer that consists of finely powdered iron and a chemical, which is usually sal ammoniac. On the job, the mixture of powders is first mixed with water and is then brushed into the surface of the concrete. The iron in the mixture oxidizes, or rusts, in the presence of water; and the rusting is hastened by the presence of the chemical. The resulting iron oxide occupies nearly eight times the volume of the original pulverized iron. Consequently, it tends to fill the pores into which it has penetrated and thus to prevent the passage of water.

In the case of a floor, the waterproof coating is usually protected by a layer of cement mortar. The protecting course of mortar should be at least 1 inch thick, and it should be carried up the walls for at least 6 inches. If both the walls and the floor are being waterproofed, the walls should be treated first, to within 6 inches of the floor, and the floor waterproofing

should then be extended up the walls so as to meet the previous work.

66. Membrane Method.—In the membrane method of waterproofing the cellar floor and walls are enclosed by a waterproof covering, which usually consists of one or more layers, called plies. Each ply is made up of two parts: (1) a web, which is composed of felt, burlap, or cotton cloth that is saturated with asphalt or coal-tar pitch; and (2) a film of cement, asphalt or coal-tar pitch, which unites the webs.

Membranes are always placed on the wet side—usually the outside—of the masonry. The membrane then keeps the masonry dry, and the pressure exerted by the water tends to press the membrane more firmly against the masonry. If the membrane were placed on the inside surface of the masonry, the water pressure coming from the outside would tend to push the membrane away from the masonry, and the moisture from the outside would enter the masonry and would tend to rise through the pores in the masonry by capillary action.

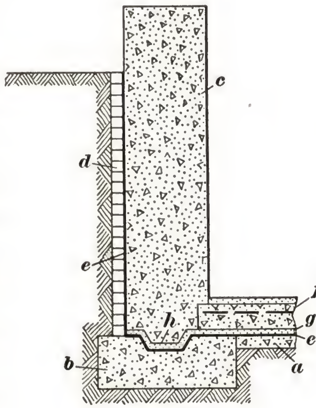


FIG. 27

67. Wherever the working space outside a basement wall is limited or the membrane is likely to be injured by the earth backfilling after it has been laid on the wall, the usual method of construction is as shown in Fig. 27. The first step is to lay the concrete subfloor *a* and the footing *b* for the basement wall *c*, and to erect the auxiliary brick wall *d* on the footing. The waterproofing membrane *e* is then placed in a continuous sheet on the subfloor *a*, on the part of the footing *b* that is to be inside the wall *d*, and on that wall. In order to protect the membrane on the horizontal surface until the basement floor *f* and the wall *c* are built, a 1-inch layer *g* of portland-cement mortar is spread over the waterproofing as soon as it is laid.

Sometimes, a key h is formed between the wall c and the footing b, for the purpose of preventing the wall from sliding inward under the action of the external pressure.

68. The construction of an auxiliary brick wall, as d in Fig. 27, entails considerable expense. Therefore, where enough room is available to place the waterproofing membrane outside the basement wall after that wall is built, the construction illustrated in Fig. 28 is usually preferred. Here the planks a and b in view (a) serve the purpose of holding up temporarily the

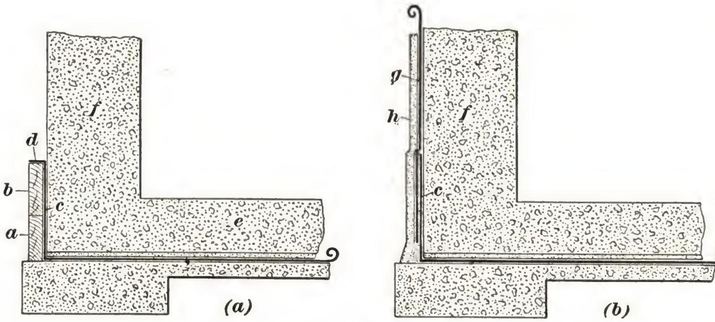


FIG. 28

vertical part c of the membrane, the lip d of which is fastened to the edge of the upper plank. The floor e and the wall f are then concreted in the usual manner. When the wall forms have been removed, the planks a and b are carefully taken out so as not to injure the membrane. As indicated in view (b), the membrane g may then be applied to the outer surface of the concrete wall f. This membrane laps over the membrane c already in place and is cemented to it by plying cement. Finally, a 1-inch coat h of portland-cement mortar is placed over the entire outside surface of the membrane in order to protect it.

SIDEWALK VAULTS

CONSTRUCTION OF VAULTS

69. General Features of Vaults.—The construction of vaults under sidewalks is permitted in nearly all cities. A vault usually extends to the street curb and to the same depth as the lowest floor in the building. Where there is a sub-basement in the building, the vault is divided into stories that correspond to the basement and subbasement. However, a vault is sometimes provided merely for the purpose of admitting light and air to the basement and subbasement. Provision for ventilating and lighting a vault may be made by installing suitable devices in the sidewalk, which forms the roof of the vault, or in the foundation wall. A sidewalk vault may be separated from the basement by the basement wall, in which there is a door for entering and leaving the vault; or the vault may be an extension of the basement, as indicated in Fig. 21.

70. Uses of Vaults.—A vault that is separated from the basement by a wall is generally used for the storage of coal or merchandise or as a means of getting materials into the basement. A vault that is an extension of the basement may be used for the same purpose as the basement. In office buildings, vaults are frequently utilized for mechanical equipment, such as motors and pumps that supply water to the plumbing fixtures, motors that operate the vacuum sweeper system, and the sidewalk lifts and elevators. In mercantile buildings, where the basement is often used for the sale of merchandise, a vault provides a valuable addition to the floor space.

71. Construction of Sidewalk Over Vault.—Air can enter a vault by means of ventilators, such as those shown at *e* in Fig. 21. Also, light can be admitted through the sidewalk by

the provision of panels *f*, which contain small pieces of glass, known as vault lights or sidewalk lights. In the building that is illustrated, part of the basement is occupied by the steam boiler *g*. The coal is dumped through the coal hole *h* in the sidewalk into the storage bin *i* in the vault. Access to the vault from the sidewalk is furnished by means of the ladder *j* and the doors *k*, which are directly over the ladder. The doors *l* are provided for the removal of ashes by means of a sidewalk lift. A city fire hydrant is shown at *m*. The lower portion of the hydrant is set in a recess *s* in the vault wall, in order that it will be accessible from the roadway in case repairs are necessary.

Various methods are adopted for framing the beams that support the sidewalk and for constructing the sidewalk. In Fig. 21, the sidewalk surfacing is supported by the steel beams *n*, *o*, and *t* and by a reinforced-concrete slab *p*, which spans between those beams. The reinforcing bars *q* and *r* run parallel and perpendicular to the curb. A waterproofing membrane *u* is laid between the slab *p* and the sidewalk surfacing in order to prevent leakage of water from the sidewalk into the vault.

VAULT LIGHTS

72. Use of Vault Lights.—As shown in Fig. 21 at *f*, vault lights, or sidewalk lights, are placed in the sidewalk over a vault to permit daylight to enter the vault or adjacent parts of the basement. These lights contain round or square pieces of glass, called *lenses,* which are set in mortar that is made strong enough by the use of steel reinforcing rods or is supported by steel or cast-iron frames. Sidewalk doors, covers of ventilators, and coal-hole covers also may be provided with lenses instead of being made of solid metal.

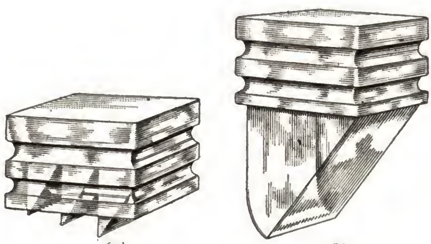
73. Lenses.—Lenses for vault lights are made of special glass that has a high degree of brilliance, toughness, and resilience. They are of two general forms. Those of one form have flat tops and bottoms, as shown in Fig. 29, (*a*), (*b*) and (*c*), and are known as plain lenses, or flat lenses. In lenses of the other form, such as those shown in Fig. 30, (*a*), and

(*b*), the tops are flat but the bottoms have sloping extensions, called *prisms,* or *pendants.* Plain lenses do not deflect the rays of light that pass through them and are generally used over vaults that are separated from the basements by walls. Lenses with prisms deflect the rays of light that pass through them and when they are used over a vault that is an extension of the basement, they transmit light to both the vault and the adjacent parts of the basement.

(*a*) (*b*) (*c*)

Fig. 29

The edges of the lenses are grooved, as shown in Figs. 29 and 30, to give them a better grip in the mortar filling. The lens shown in Fig. 29 (*c*) is used with a metal wire *a* that fits in a continuous groove in the glass. This wire is held firmly in the mortar and forms a screw thread by means of which the lens can be unscrewed, if it becomes broken, and a new one can be inserted without damaging the mortar.



(*a*) (*b*)

Fig. 30

74. Construction of Vault-Light Sidewalks.—A common type of vault-light construction in which a cast-iron frame is used is illustrated in Fig. 31. A plan is shown in view (*a*), a cross-

section in view (b), and an enlarged detail in view (c). The outside metal frame a, which is stiffened by ribs b, is set in the concrete sidewalk. The inner metal frame c, containing the

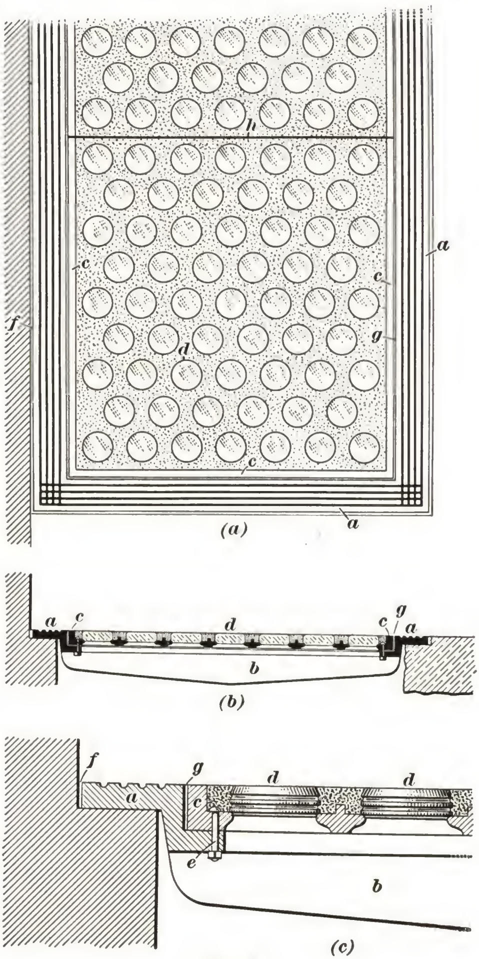
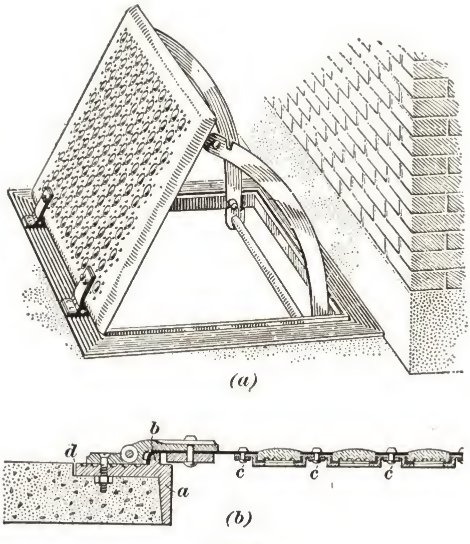


FIG. 31

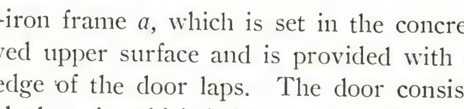
lenses d embedded in mortar, is set in the frame a and is fastened to that frame by bolts e. The joints f between the frame a and the wall, the joints g between the frames a and c, and the joints

h, view (*a*), between adjacent sections of the frame *c* are filled with elastic cement.

75. A sidewalk door that is intended to admit both air and light to a vault is shown in Fig. 32, in perspective in view (*a*) and in cross-section in view (*b*). The door is made of sheet steel, and lenses to admit light to the vault are set in holes that are provided to receive them. Air is admitted by opening the door. It is therefore equipped with hinges and an operating device by means of which it can be opened or closed from within the vault.



(*a*)



(*b*)

Fig. 32

The cast-iron frame *a*, which is set in the concrete sidewalk, has a grooved upper surface and is provided with a lip *b* over which the edge of the door laps. The door consists of a continuous steel plate, in which holes are cut where the lenses are to be located, and also of separate pieces *c* of sheet metal which are bolted to the main plate and in which the lenses are secured by means of a cement made of tar, and sulfur. The joint *d* between the frame *a* and the sidewalk is also filled with cement.

76. In Fig. 33 is shown a type of vault-light construction in which the lenses are supported by a frame composed of the steel members *a* and *b*. These members are spaced so as to leave room for the lenses and also for cement mortar, which is poured between the lenses and around the steel after the lenses are set in place.

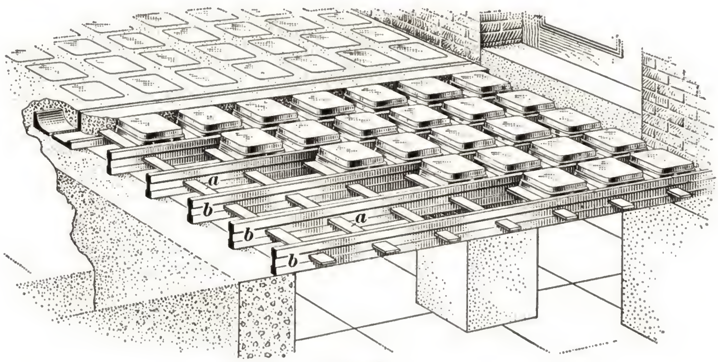


FIG. 33

A sheet-metal frame of the type shown in Fig. 34 is often used. This frame not only supports the lenses, which are set in holes in it, but it also serves as a form on which the mortar is supported while hardening. The lenses are set in place, the reinforcing bars *a* are laid on supports in the manner indicated, and the mortar is then poured.

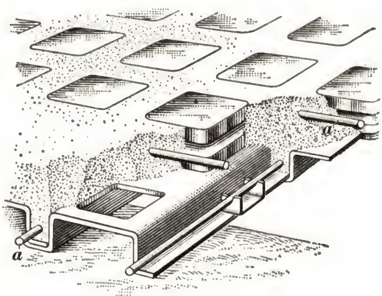


FIG. 34

In the construction shown in Fig. 35, no metal frame is used for the support of the mortar, but sufficient strength is pro-

vided by reinforcing the mortar with steel rods. Wooden forms for the temporary support of the lenses and mortar are first constructed, the lenses and reinforcing rods are set in position, and the mortar is poured. When the mortar develops sufficient strength, the forms are removed.

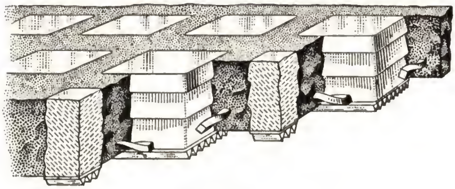


Fig. 35

77. The surfaces of the glass lenses and also plain surfaces of iron or mortar become very slippery when wet. Therefore, the area of each lens is usually made comparatively small; the surfaces of iron are finished rough and are formed with grooves; and mortar surfaces are treated with non-slip materials. Thus, carborundum grit or similar material is sometimes pressed into the mortar around the lenses in order that the surface will afford a good footing for pedestrians.

The mortar filling is often made more durable by sprinkling granite or trap-rock chips, limestone grit, or similar hard material over the surface and pressing the particles into the mortar before it hardens. The mortar between the lenses in the vault-light portions of the sidewalk and the concrete in the adjacent portions of the sidewalk are usually deposited at the same time and are given the same kind of finish.

STONE MASONRY

Serial 1059 Edition 3

TERMS USED IN STONE MASONRY

1. Parts of a Stone.—The names given to the parts of a block of stone when prepared for a structure are here defined. The **face** is the surface that will be exposed to view. The **back** is opposite the face, and parallel, or nearly so, to it. The upper and the lower horizontal surfaces (as laid) are called **beds,** and are distinguished, respectively, as the *top bed* and the *bottom bed*. The height, or distance between the top and bottom beds, is called the **rise** or **build.** The vertical sides at right angles to the face are called the **joints.** The four edges of the face, when they have been sharply defined by the use of the chisel, are termed **pitch lines** or **arrises.**

A stone used at the corner of a wall and showing two faces is called a **quoin.** Small pieces of irregular-shaped stone are called **spalls.** A cut stone is said to be *spalled* when a portion of the edge has been broken off.

When the blocks of stone are so large as to require machinery to raise them, a hole, of the shape of an inverted truncated wedge, is cut in the center of the top bed to receive a device called a **lewis,** Fig. 1, to which the hoisting rope from the derrick is attached. Otherwise, two holes are cut obliquely in the top bed to receive bolts with eyes for the same purpose. When the device called a **dog,** or **grab,** is used, small holes are drilled in the sides of the stone, to receive its points. The holes should be so placed as not to mar the appearance or affect the durability or strength of the stone, and should never be placed in the faces of fine cut stones. The holes are variously designated as *lewis holes, grab holes, dog holes,* etc.

2. Parts of a Wall.—The **footings** of a wall are the projecting courses at the base of the wall, employed for the purpose of distributing the weight over an increased area of soil and thereby diminishing the liability to vertical settlement from compression of the ground.

The **face** is the portion of the wall exposed to view, and the **back** is the inner portion.

3. Each horizontal row or layer of stone is called a **course.** Some of the courses have particular names. The **plinth,** also called the **water-table,** is a projecting course placed at or near the ground line. The **belt-courses** or **string-courses** are horizontal courses placed at intervals on the face of a building for the purpose of ornament. The course from which an arch springs is called the **springing course.** A **stretching course,** or **stretcher course,** is a course composed entirely of stretchers. A **header course** is a course composed of headers. A **bonding course** is a course composed of bond stones. The terms *stretcher, header,* and *bond* are defined further on. The **corbel course** is composed of pieces of stone projecting from the face of the wall, for the purpose of supporting a course that projects still farther. The **cornice** is the ornamental course or courses generally set at or near the top of the wall.

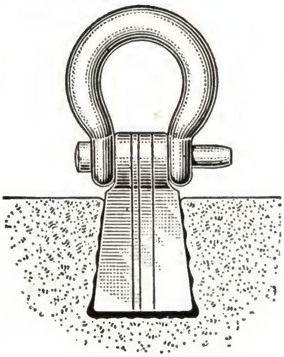


FIG. 1

4. The **coping** is the finishing course at the top of the wall, and consists of large stones projecting slightly over the wall at both sides, accurately bedded on the wall and joined to one another with cement mortar. The coping is used to shelter the mortar in the interior of the wall from the weather, and to protect, by its weight, the smaller stones below it from being knocked off or picked out. Coping stones should be so shaped that water may rapidly run off them. For coping, long stones are preferable to short ones, because the number of top

joints will be diminished and the mass beneath the coping will be better protected. Additional stability is given to a coping by so connecting the stones that it will be impossible to lift one of them without at the same time lifting the ends of the two stones next to it. This is done either by means of metal **clamps,** or **cramps,** which have the ends turned at right angles to the body of the bar, and are inserted in holes cut in the stones and fixed there with lead, or by means of **dowels** of wrought iron, cast iron, copper, or hard stone. The metal dowels are inferior in durability to those of hard stone, although they are superior in strength. They are fastened by pouring melted lead or sulphur around them. Copper is strong and durable, but expensive. The stone dowels are small prismatic or cylindrical blocks, each of which fits into a pair of opposite holes in the contiguous ends of a pair of coping stones and is fixed with cement mortar.

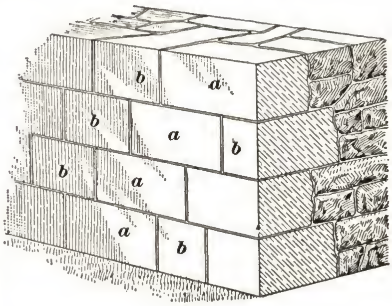


FIG. 2

The under edge of the coping should be provided with a **drip;** that is, grooved so that the water falling on it will not run back on the wall, but will drop from the edge.

5. The term **bond** is applied to the method adopted for placing the stones or bricks in a wall, by lapping them over one another, so as to prevent the vertical joints from forming a continuous straight line, the occurrence of which would produce a weak and easily separable structure. A good bond breaks the vertical joints, both in the length and in the thickness of the wall.

Various methods are employed to form the bond. The method by **headers and stretchers,** in which the vertical joints of each course alternate with the vertical joints of the courses above and below it, is the simplest and the most commonly used. In this method, shown in Fig. 2, the blocks of

each course are laid alternately with their greatest and least dimensions to the face of the wall. Those that present the longest dimension, as *a,* are termed **stretchers;** the others, as *b,* are termed **headers.** This arrangement of headers and stretchers is termed the **longitudinal bond.** Its object is to distribute the load or pressure over an increasing area downwards to the foundation. The extent to which the blocks should overlap or break joint is usually from one to one and one-half times the rise, or height, of the course.

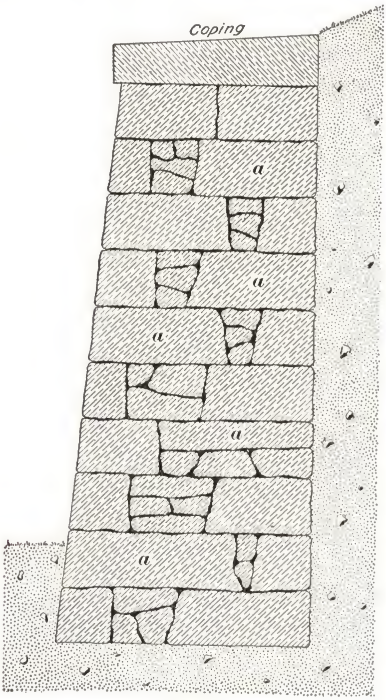


Fig. 3

The bond across the thickness of the wall is of more importance than the longitudinal bond; its object is to tie the face and the back of the wall together; this is effected by the headers. A header that extends from face to back is termed a **through bond.** When walls exceed 3 feet in thickness, it is not advisable to use through bonds, because of the liability of the long stone to become broken in the middle by unequal settlement; in its place headers that reach only a part of the distance are used. In this case, they are called **binders** and should extend from each face about two-thirds of the thickness of the wall, as shown at *a,* Fig. 3; they should be arranged so as to cross each other alternately. The strongest bond in masonry composed of rectangular stones is that in which each course at the face of the wall contains a header and a stretcher alternately, the outer end of each header resting on the middle of a stretcher in the course below; so that rather more than one-third of the area

of the face consists of ends of headers. This proportion may be deviated from when circumstances require it; but in every case it is advisable that the ends of headers should form not less than one-fourth or one-fifth of the whole area of the face of the wall.

6. Joints.—The mortar layers between the stones are called the **joints.** The horizontal joints are called **bed joints,** or simply **beds.** The end joints are called **vertical joints.** When the term *joint* is used without any qualification, a vertical joint is meant. Excessively thick joints should be avoided. For ashlar masonry, joints should be about $\frac{3}{16}$ to $\frac{1}{2}$ inch thick; for rubble masonry, they vary according to the character of the work.

Joints of masonry are finished in different ways, with the object of presenting a neat appearance and of preventing

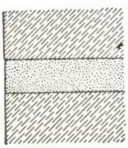


Fig. 4

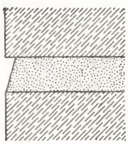


Fig. 5

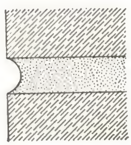


Fig. 6

water from entering the wall. The joints most used in ashlar masonry are: (1) **Flush joints,** Fig. 4, in which the mortar is pressed flat with the trowel, and the surface of the joint is flush with the face of the wall. (2) **Struck joints,** Fig. 5, formed by pressing or striking back with the trowel the upper portion of the joint, while the mortar is moist, so as to form an outer sloping surface from the bottom of the upper course to the top of the lower course. This joint is also called a **weathered joint.** Masons generally form this joint so that it slopes inwards, thus leaving the upper arris of the lower course bare and exposed to the action of the weather. The reason for forming the joint in this manner is that the work is more easily done. (3) **Keyed joints,** or **tooled joints,** Fig. 6, formed by drawing a curved iron key or jointer along the center of the flushed joint and pressing it hard so that the mortar is driven in beyond the face of the wall. A groove of

curved section is thus formed, having its surface hardened by the pressure.

7. Among other forms of joints that are used is the *raised, ruled,* or *rodded joint,* the purpose of which is to give a uniformity of effect in the joints that is not natural to rubble. Rubble treated with raised joints looks as if all the stones had straight edges and evenly cut joints, whereas, the effect is due entirely to the treatment of the mortar joints. Fig. 7 (*a*) shows a sample of this kind of jointing. The irregular stones *a* are built into the wall, and when the wall is finished they are pointed up as nearly flush as possible, as shown at *b,*

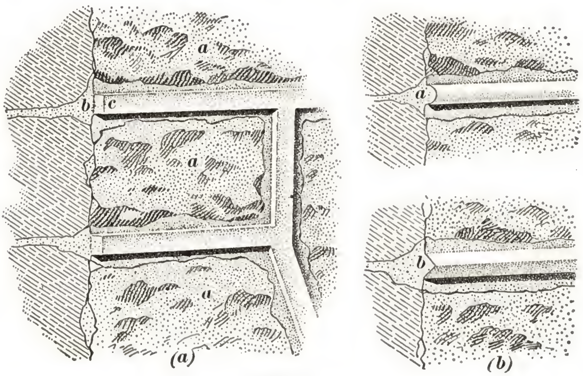


Fig. 7

and the raised joint is formed as shown at *c*. In order to make these joints, a sufficient quantity of mortar is placed along the joint and pressed down to an even surface. By the use of a straightedge of wood and a small trowel, these raised joints are cut straight on each edge, forming a straight rectangular projection as at *c*. The stones should be hammer-dressed to make the edge of the stone approximately straight so that the joints will not be too wide. The general effect of this kind of pointing is illustrated in Fig. 8.

Another form of a raised joint is illustrated in Fig. 7 (*b*), where the raised portion of the joint is curved or **beaded,** as shown at *a,* or **V**-*shaped,* as at *b*. A joint such as this is formed by a tool with a hollow half-round or a **V**-shaped edge.

8. Pointing a piece of masonry consists in scraping out the mortar in which the stone was laid, from the face of the joints for a depth of from $\frac{1}{2}$ inch to 1 inch, and filling the groove so made with fresh Portland-cement mortar, made of one part of cement and one part of sand. The necessity for pointing arises from the fact that the exposed edges of the joints are always deficient in density and hardness, and the mortar near the surface of the joint is specially subject to dislodgment, since the contraction and expansion of the masonry

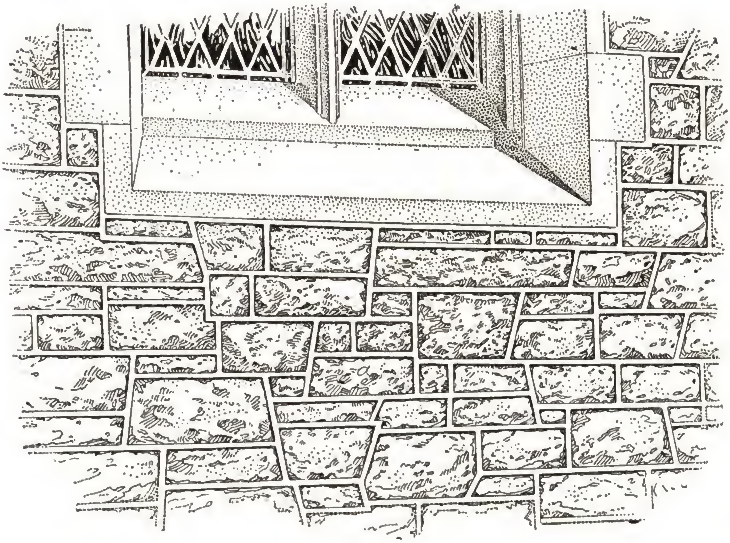


FIG. 8

are likely either to separate the stone from the mortar or to crack the mortar in the joint, thus permitting the entrance of rainwater, which by freezing forces the mortar from the joints.

The pointing mortar should be mixed with just enough water to hold it together. Before applying the mortar, the joint must be well cleaned by scraping and brushing out the loose mortar, then thoroughly saturated with water and maintained in such a condition of dampness that the stones will neither absorb water from the mortar nor impart any to it. Walls should not be allowed to dry too rapidly after pointing. Pointing should not

be done either during freezing or during excessively hot weather. The pointing mortar is applied with a mason's trowel, and well pressed into the joints. In the very best work, the surface of the mortar is rubbed smooth with a jointer. The form given to the finished joint may be any of those described in Art. **6.** Pointing with colored mortar is frequently employed to improve the appearance of the work. Various colors are used, as white, black, red, brown, etc., different-colored pigments being added to the mortar to produce the required color. Many authorities consider that pointing is not advisable for new work, as the joints so formed are not so enduring as those finished at the time the masonry is built. Pointing is, moreover, often resorted to when it is intended to give the work a superior appearance and also to conceal defects in inferior work.

CLASSES OF MASONRY

RUBBLE MASONRY

9. The stonework entering into the construction of buildings may be divided into three classes: *rubble, ashlar,* and *trimmings.* Of these, rubble will be described first.

Rubble, or **rubblework,** is stonework that is built of rough irregular-shaped stones as they come from the quarry, these stones being roughly trimmed, when necessary, to fit against each other in the wall. This work is done by means of a mason's hammer. The stones should be placed on their widest beds, so that they may not be crushed or act as wedges and force out the adjacent work. The side joints should not form an angle with the bed joint sharper than 60°. Some quarries contain stratified stone that can be quarried so as to have two faces more or less parallel to each other. These flat surfaces should be the beds of the stone. Stronger and better walls can be made with stones of this kind than can be made of stones that have no stratification. Rubblework is generally used for foundations and walls that will not be visible on the

outside of the finished building. It is also used for backing more expensive masonry, such as ashlar work, referred to later.

The stones that are generally used for rubblework are those which are easily obtained in the locality. These may be field stones or stone quarried from an adjacent quarry, and may be any of the well-known kinds of stone such as granite, limestone, sandstone, conglomerate, etc.

Rubble is also used for the finished surface of an exposed wall. With care in its erection and by using stone of fine

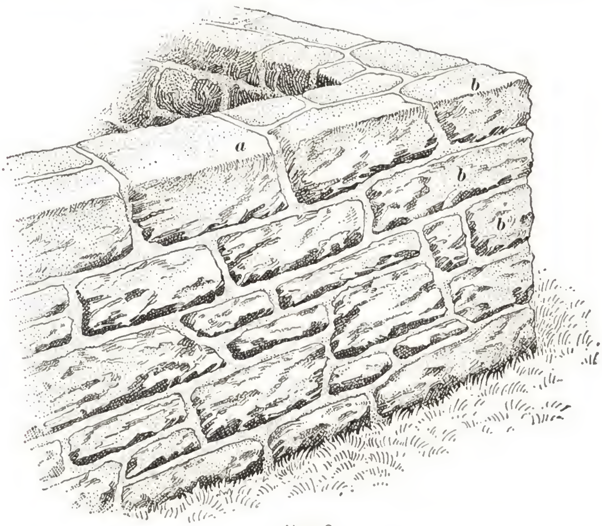


FIG. 9

appearance and color it forms a very handsome wall. In this case the joints must be carefully made and the stones arranged in the wall according to some pleasing design.

10. Fig. 9 represents a good type of a rubble wall formed of quarried stone. Where this wall appears above grade, the stones are dressed with some care. This is not necessary where the wall is below grade. The wall is bonded, or tied together, by *bond stones,* as shown at *a* in Fig. 9. One of these bond stones should occur in every 4 or 5 square feet of the exposed surface of the wall. Where the wall is 2 feet or

more in thickness, these bond stones generally extend not more than two-thirds or three-fourths of the distance through the wall, as was shown in Fig. 3.

The stones should be laid *breaking joints,* that is, the vertical joints should not be over each other in any two courses, with few exceptions. The stones at the corners of this wall are generally of a longer size and are laid up in alternate courses of headers and stretchers, as shown at *b,* Fig. 9.

The mortar used for all rubblework which is built below the surface of the soil should be a cement mortar with not more

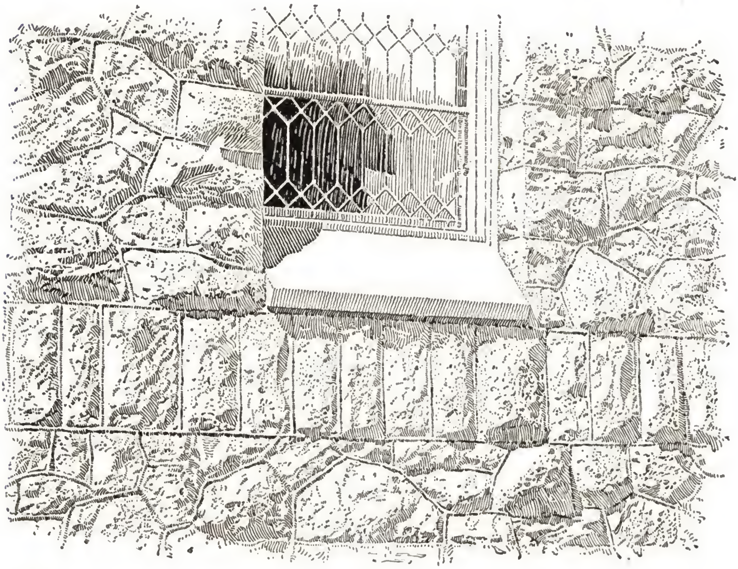


Fig. 10

than a small percentage of lime mixed with it. A mortar consisting of equal parts of lime and cement may be used for rubble above grade. This is less expensive than cement mortar and is generally sufficiently strong for the purpose.

Owing to the irregular shapes of the stones, cavities are naturally formed in the middle of the wall. These are filled up with mortar and spalls. The bed for each stone should be prepared by filling in any cavities in this manner. The joints at

the surface of the wall are frequently pointed with colored mortar and finished with a raised joint.

11. Fig. 10 shows a form of rubble masonry which is very effective for use where the wall is visible. The stones are neatly fitted together, and at the same time the individual stones are irregular in shape. The joints form an irregular pattern over the entire surface of the wall, and should be as nearly as possible of uniform thickness. The individual stones are carefully dressed with a hammer, and no spalls or chips

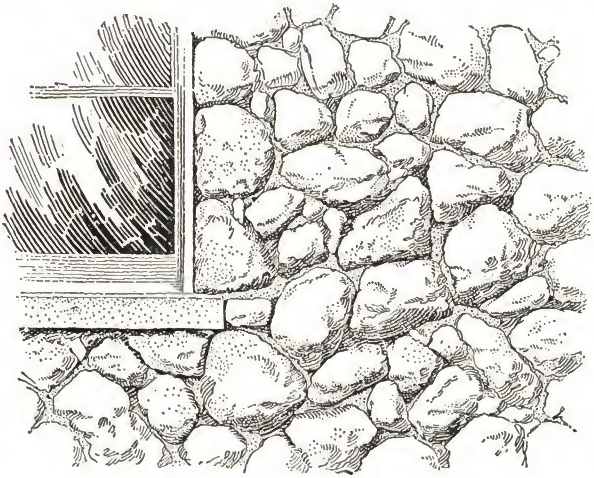


FIG. 11

should show in the face of the wall. The work required to dress the stones makes this type of wall rather an expensive one.

12. Field-Stone Walls.—Fig. 11 shows a rubble wall built of field stone. The stones for such a wall are collected from adjacent fields and are generally round and irregular in shape. It is necessary, in order that this wall shall have sufficient strength, that a strong cement mortar be used in its construction.

13. Walls With Brick Quoins.—Walls are sometimes built having brick quoins *a*, Fig. 12, at the corners of the wall,

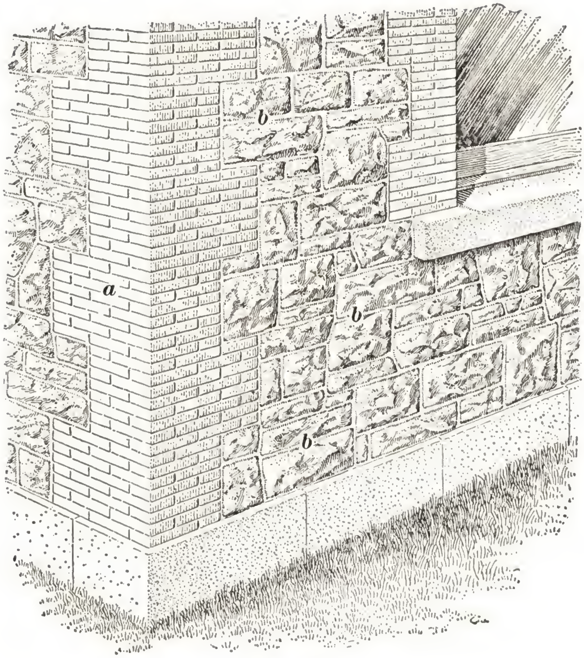


FIG. 12

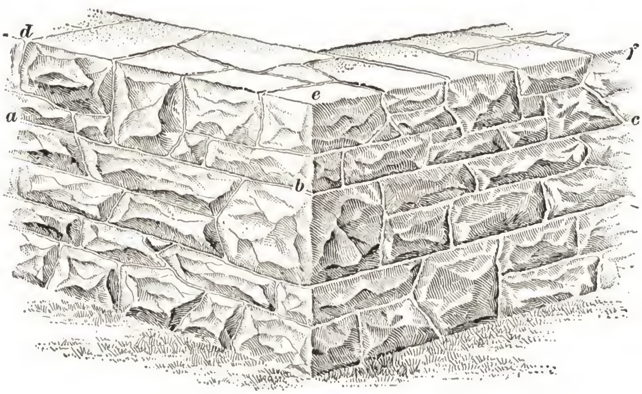


FIG. 13

and also brick quoins around the window and door openings. In the example shown, the top and bottom beds of the stones are level, as at *b, b,* an arrangement cheaply obtained where the stones split readily into layers with parallel beds.

14. Coursed Rubble.—Rubblework is sometimes built in courses between horizontal beds. These courses are from 2 to 4 feet in height, and the masonry is finished by a level bed at this height, and a new course is started at this level. Fig. 13 represents three courses of a coursed rubble wall, two of these beds being shown at *a b c* and *d e f*.

ASHLAR

15. Classification of Ashlar.—Ashlar is a facing made of squared stones, and is used to face brick walls or stone walls of cheaper construction. These brick or stone walls are gen-

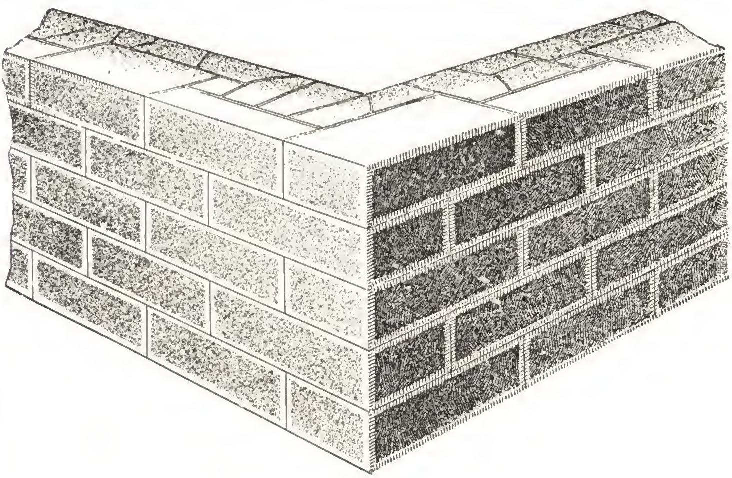


FIG. 14

erally referred to as the backing. The term ashlar is also applied to the stones that constitute this facing. The exposed surface of the stones can be finished in any manner desired, but to be considered ashlar the joints between the stones must

be horizontal and vertical. There are two general classes of ashlar, namely, *coursed ashlar* and *broken ashlar.*

16. Coursed Ashlar.—Coursed ashlar is that class in which all the stones in each course are of the same height and the horizontal joints are continuous around the building. Good examples of this class of work are shown in Figs. 14, 15, 16, and 17.

In Fig. 14 the stones show equal-size faces in the wall and each stone has a margin or draft line cut around the edges, while the main surface is fine-pointed. In Fig. 15 is shown

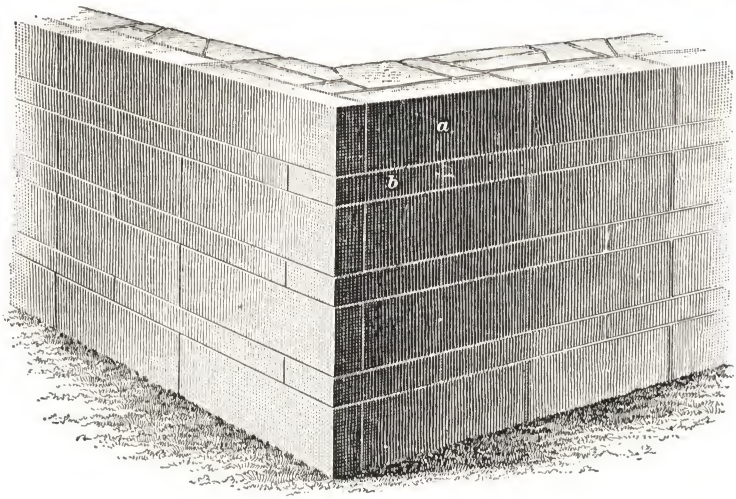


FIG. 15

ashlar in which the courses are in two different heights *a* and *b*, which produces a banded effect. An ashlar wall with elaborately cut quoins and a belt-course is shown in Fig. 16. The quoins and stones of the belt-course are finished in what is called vermiculated work. Work finished in this style is very costly.

17. Block-in-Course Ashlar.—In *block-in-course,* or *blocked-course,* ashlar work, shown in Fig. 17, all blocks of stone are cut the same height but in different lengths, and no attempt is made to have the joints come over one another in

alternate courses. As a rule, this style of work looks best in rock-faced finish, but any finish desired may be used.

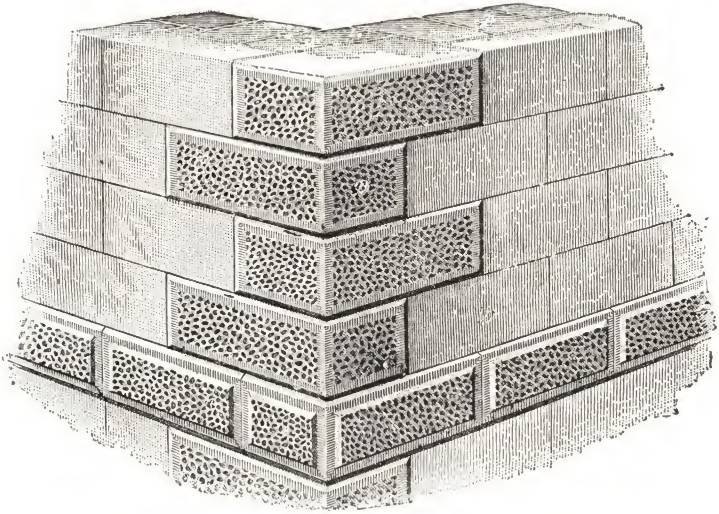


Fig. 16

18. Random-Coursed Ashlar.—The method of laying random-coursed ashlar walls is illustrated in Fig. 18. In this class of work, no attempt is made to have the vertical joints

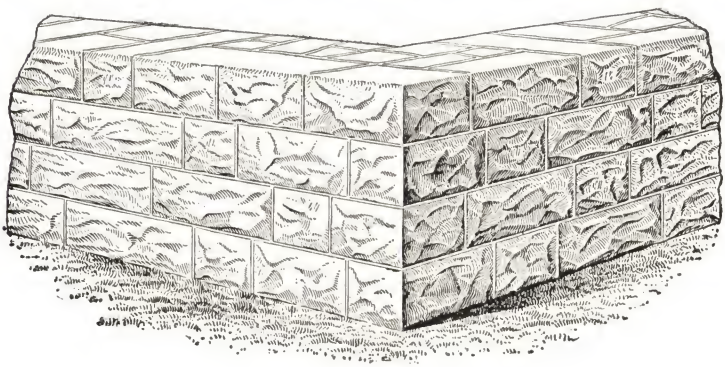


Fig. 17

over one another in alternate courses, and it has only a general arrangement in courses, as shown.

19. Broken Ashlar.—In **broken ashlar,** sometimes called **random ashlar,** no attempt is made to have the stone run in courses, but each block is cut for the location in which it is to go. It generally takes more time to build the broken ashlar than coursed work, and hence it is more costly, owing to the increased amount of labor required to fit and lay the different sizes of stone. This kind of ashlar, when properly executed, presents a pleasing appearance. It is generally laid up as rock-faced work, but in some cases it is tooled or hammer-dressed. It should have no horizontal joints more than 4 feet

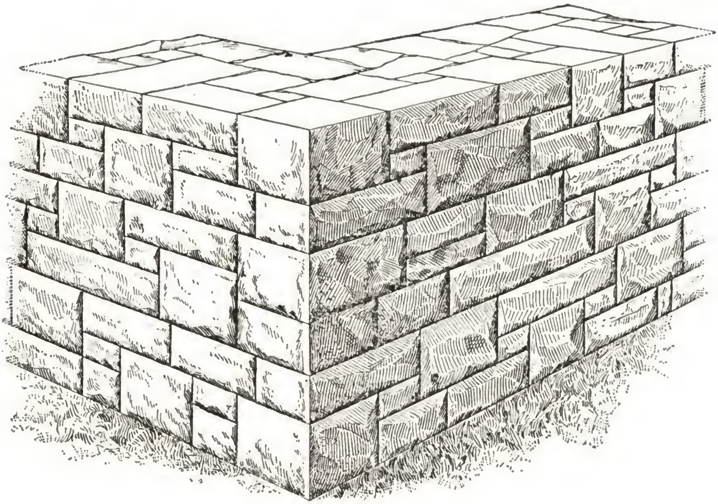


Fig. 18

long, and several sizes of stone should be used. Fig. 19 shows an ordinary broken-ashlar wall, in which the quoins are indicated at *a* and the ashlar facing at *b*.

20. Dressing Ashlar.—Ashlar may be dressed in any of the finishes described and illustrated in the Section on *Building Stone*. Very hard stones, such as granite, trap, etc., are generally given a rock-faced treatment, as elaborate cutting on these stones is very expensive. Granites are, however, sometimes finished with a smooth surface and may even be polished. This finish is used in the lower stories of fine business buildings.

Soft stones, such as limestone, which can be cut readily, are generally finished with 6, 8, or 10 cut work or with rubbed surfaces. Carving is also comparatively cheap when done in soft stones, and when such carving is required soft limestone or sandstone is generally used. Carving done in granite is very expensive.

21. Laying Out Ashlar.—When ashlar in regular courses and sizes is to be used, drawings should be made show-

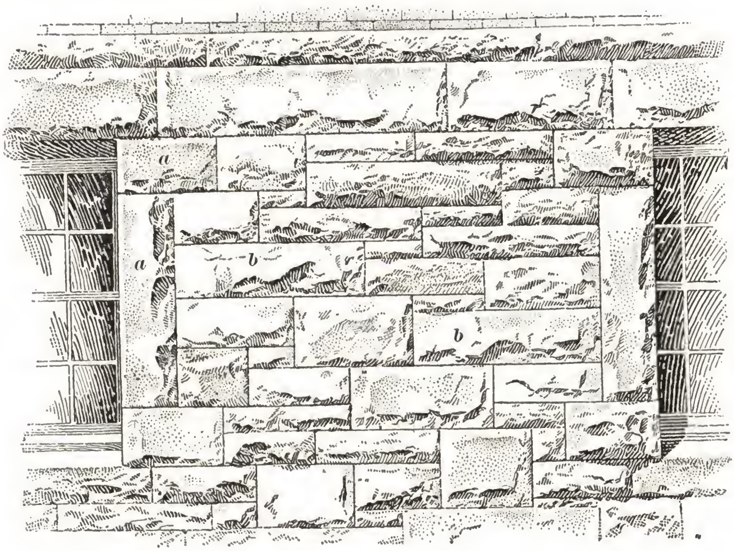


FIG. 19

ing each stone, the heights of the courses, the location of the stones, and other necessary details, as described in the Section on *Building Stone*. The drawings for important buildings usually show every stone. A drawing of this character is shown in Fig. 20. In this drawing it will be noted that individual stones are shown by lines extending from their diagonally opposite corners. These diagonal lines are shown in the rectangular face blocks of the pilaster and on the stones that extend behind the pilaster. The parts of the stones behind the pilaster are indicated by dotted diagonal lines. The stones of

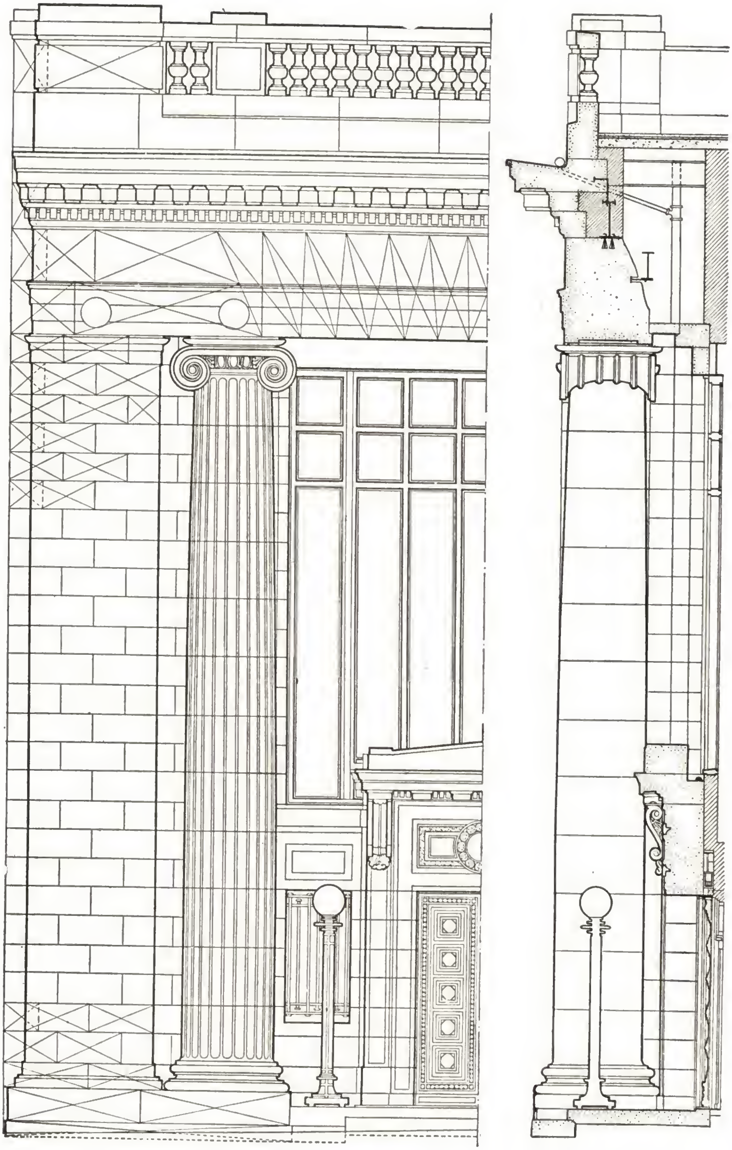


FIG. 20

the flat arch over the opening between the columns are shown by diagonal lines to indicate that they are single stones extending from the top of the column to the bottom of the cornice. When broken ashlar is used, it is only necessary to show the quoins and jambs on the drawings, together with enough of the broken ashlar to indicate the character of the work desired.

22. Backing.—The expense of ashlar masonry is such that it is commonly used merely as a facing, being backed with either rubble masonry or brickwork. In many cases the backing is the real wall and the ashlar is a veneering anchored to this

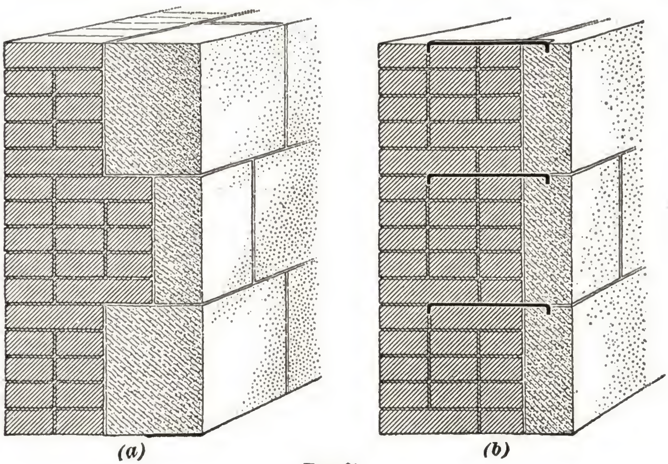


FIG. 21

wall, as shown in Fig. 21. In the New York building code, for example, veneering such as shown in (*b*) is not counted in the thickness of the wall when estimating the bearing strength of the wall. If, however, the ashlar is alternately 8 inches and 4 inches thick and is bonded to the wall, as shown in (*a*), it is considered as having a bearing value, and the wall need be made only as thick as would be required if the wall were entirely of brick.

Both stone and brick are used for backing, but in most cases brick is more convenient, and, hence, is more extensively used When using brick for the backing, the backing should never be

less than 8 inches thick. The backing of ashlar, whether of stone or of brick, should be laid in cement mortar.

When stratified stone with flat parallel beds can be obtained, it can be used to advantage, as it forms a very good backing for ashlar work. Irregular rubble walls should not be used for backing in walls of dwellings higher than two or three stories. All backing, whether of brick or stone, should be carried up at the same time and built in courses of the same thickness as the ashlar in the manner illustrated in Fig. 21.

If the courses are not over 12 inches high, they are usually bonded sufficiently to the backing by making every other course thicker, as in Fig. 21 (*a*).

23. Fastening Thin Ashlar.—Ashlar facing of from 2 to 4 inches in thickness is often used, as shown in Fig. 21 (*b*), especially when marble or other expensive stone is employed in the construction. In such cases, each piece of ashlar should be tied to the backing, in the manner shown, by at least one anchor similar to that shown in Fig. 22. If the stones are more than 3 feet long, two anchors are generally used. All iron clamps, or anchors, should be either galvanized or dipped in hot tar or asphalt, to prevent the formation of rust on them.

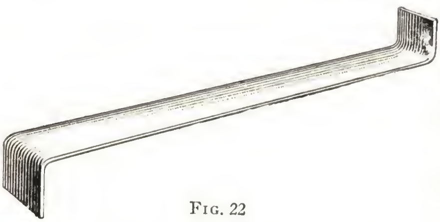


FIG. 22

When a wall is faced with thin ashlar, the effective bearing strength is only that given by the thickness of the brick or stone backing, the facing not being relied on for that purpose.

TRIMMINGS

24. The term **trimmings,** as generally used, includes moldings, belt-courses, sills, caps, and other cut stone (except ashlar) used for ornamental purposes.

The stones for such work should be of good quality, having the beds closely dressed and the ends square and properly

matched. All washes, soffits, etc. should be cut smooth or rubbed. When a brick building is trimmed with stone, the

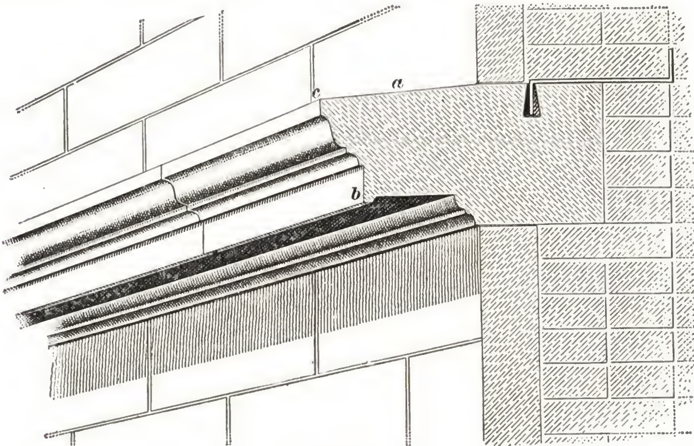


FIG. 23

stones should be designed so that their height shall be equal to that of two or more brick courses. The horizontal joints of the stonework will then coincide with the horizontal joints of the brickwork. This is important in cases where the brickwork abuts against stone quoins or jamb stones, where it is desirable to have the joints of the brickwork and stonework at the same level. It is equally important that the joints of the backing shall coincide with those of the ashlar, to allow the anchors to extend back into the wall.

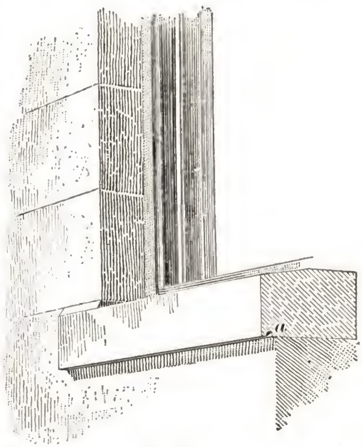


FIG. 24

25. Washes and Drips. The tops of all cornices, belt-courses, etc. should have an outward and a downward pitch from the walls, as shown at *a*, Fig. 23. Such beveled surfaces are called *washes*. If the top

is level or slopes inwards, water will collect, and in time will cause the disintegration of the mortar in the adjacent joints and finally penetrate the wall. On the under side of the cornices, etc., *drips* should be made, to prevent rainwater from flowing down the face of the wall. Such a drip is shown at *b*, Fig. 23.

Window sills should also have a drip cut in them, as shown at *a* in Fig. 24, to keep the walls below from becoming discolored by dirt washed off the sills by rain.

LINTELS

26. A **lintel** is a stone that supports the wall over a door, window, or other opening, and it sometimes bears a considerable load and should therefore be a strong and durable stone of ample size. Frequently, however, the lintel is made very thin and is not designed to support the wall above, this work being

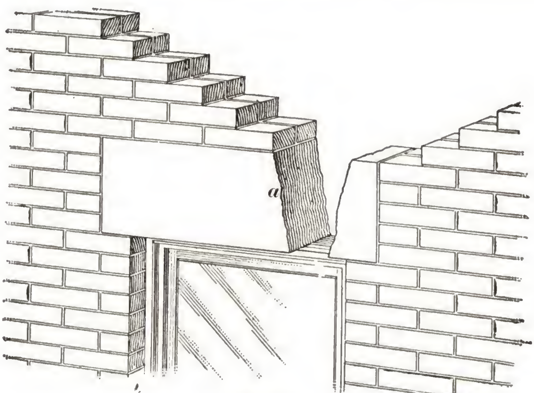


FIG. 25

done by steel beams. The ends of the stone lintels should not be built into the walls more than is necessary to give sufficient bearing, 4 to 6 inches at each end being the usual allowance.

27. A lintel may sometimes extend throughout the full thickness of the wall, as shown at *a* in Fig. 25, but ordinarily a lintel is made of the same thickness as the depth of the **reveal**, or exposed jamb of the window, *b*, which in the case of a brick

wall is about 4 inches, or the width of one brick. Where the wall is built of stone this reveal may be 6 inches, 8 inches, or more in depth, and the lintel is made of a corresponding thickness. In such cases a lintel of steel or a brick arch is placed behind the stone lintel, to support the remaining thickness of the wall above. Thus, if the wall is a 16-inch wall, and the reveal and lintel are each 6 inches, the wall to be supported by the steel lintel or brick arch would be $16-6=10$ inches.

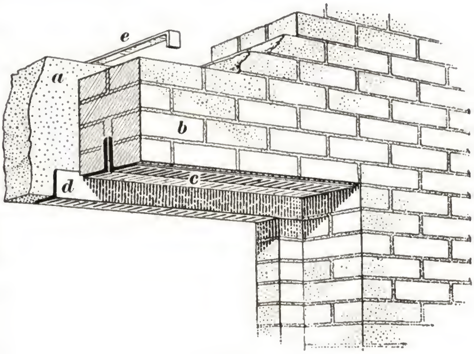


FIG. 26

In Fig. 26 is shown an example of a stone lintel *a* backed up with brickwork *b*. This brickwork is supported on two angles *c* the ends of which are built into the jambs. The lintel is supported on an angle *d*, the horizontal part of the angle being a little narrower than the thickness of the lintel, so that the edge of the angle will not be visible in the face of the wall. The lintel is tied into the wall by means of anchors, one such anchor being shown at *e*.

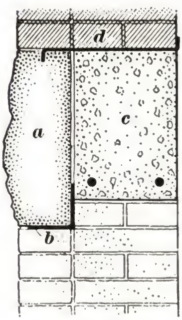


FIG. 27

In Fig. 27 a stone lintel *a* is supported by a steel angle *b*. Back of the lintel is a reinforced-concrete beam *c* which carries the weight of the wall above the lintel. An anchor *d* ties the lintel into the packing. The lintel, the angles, and the reinforcing bars extend into the brick jambs.

In Fig. 28 is shown a stone lintel *a* and a steel lintel *b*. The steel lintel consists of two angle irons which support the inner portion of the wall above the opening. The brickwork is built directly on the flanges of the angles, which serve the same purpose as the brick arch shown in Fig. 26.

28. I-Beam Supports.—Where the opening is quite large and a stone lintel is not sufficiently strong to carry its part of the load, the lintel is often supported upon **I** beams as shown in Fig. 29. The steel beams are shown at *a*, and the stone lintel is shown at *b* and rests upon the plate *c* which is riveted to the bottom flange of the outer **I** beam. The stone is sometimes cut so as to receive the plate and conceal its front edge. The steel plate should extend to within about 1 inch of the face of the lintel and the lintel should be anchored at the top by an anchor. A considerable load can be supported upon a construction of this kind. The stone, however, does not support any of the load, but is a mere facing.

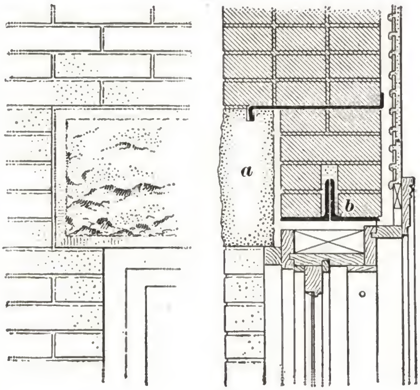


FIG. 28

Floorbeams are frequently supported upon lintels such as just described and may rest directly upon the **I** beams, as shown at *d*, or upon one of the brick courses immediately above the **I** beams.

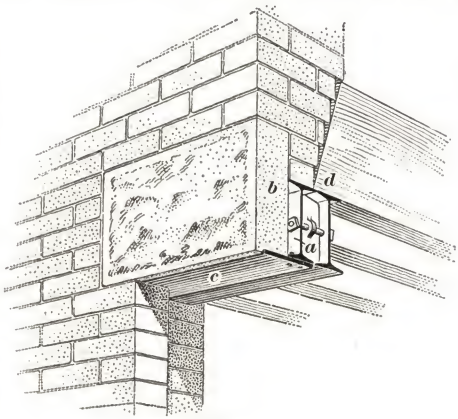


FIG. 29

It is not good practice to support the weight of a wall on both stone and steel or wooden beams, as the deflection of each material is different, making it practically impossible for each to carry its proper share of the load. The weight should preferably be borne by the steel alone, as shown in Fig. 29.

29. Built-Up Lintels.—It is sometimes necessary to use a stone lintel 10 or 12 feet long, which is difficult to obtain in a single piece. In such a case, the lintel may be made in sections, and the joints made to resemble those of an arch, as shown at *a* in Fig. 30. A stone lintel of this description is generally supported upon a steel lintel as shown at *b*, and each stone is anchored by an anchor as at *c*. The stone lintel in this case is merely the facing for the steel lintel and has no supporting value. The same treatment is used when a flat arch of brick, instead of stone, is used.

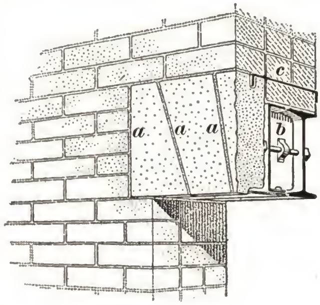


FIG. 30

SILLS

30. Lug Sills.—In masonwork, sill is the name given to the stone that forms the bottom of a window or door opening in stone or brick walls.

Lug sills, as shown in Fig. 31, have ends *a*, called *lugs*, built into the wall. These lugs should enter the walls from 2 to 4 inches, and the sill should be bedded in mortar only at the ends. If a sill is bedded solid and settlement occurs, it will probably be broken, as the pier or side walls will likely settle more than the wall under the opening. The bed joints under the sills, between the ends, should be filled when the finished walls are cleaned down. In very long sills these joints may be filled with hair felt set in the bed with a calking iron. Such a filling is weather-proof and yielding.

31. Slip sills are made just the width of the opening, and are not built into the walls. Slip sills are cheaper, but do not look so well as lug sills; besides, there are exposed vertical joints at the ends into which water is apt to penetrate. Settlement of the masonry is not liable to break a slip sill, and hence they are often used in the lower parts of heavy buildings.

32. All sills should have a bevel, or wash, of about 1 inch to the foot, extending to the back of the stone, as shown in Fig. 31. They sometimes have a straight beveled surface the full length of the sill, the lugs being omitted and the brickwork being made to fit the stone. This, however, is not good prac-

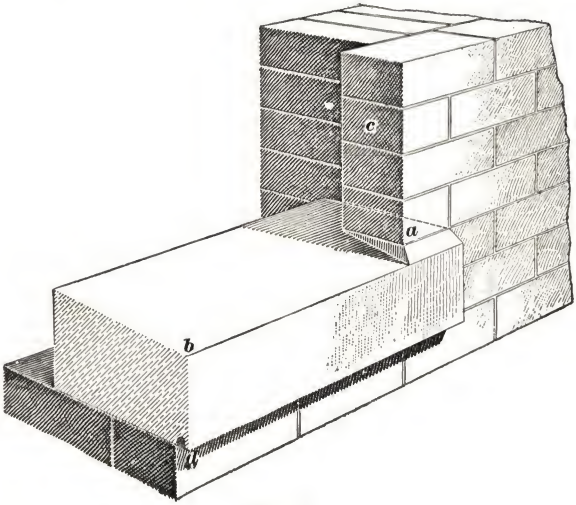


Fig. 31

tice, as the sloping upper face forms an insecure bearing for the wall resting on it. In Fig. 31 is shown the proper method of cutting the surfaces: *a* indicates the end of the lug sill, carrying the brickwork reveal *c*; *b* shows the bevel, or wash; and *d,* the drip.

COPING

33. Coping Stones.—If no cover is put on the top of a wall, water will enter the joints between the brick or the stone. For this reason, parapet walls and those constructed in a similar manner are capped with wide stones called coping. Terra cotta and concrete are also used for this purpose. The upper surface of the coping should be pitched as shown in the upper illustrations in Fig. 32, and there should be drips on the under side as shown. Sometimes a flat flagstone is used as a

coping, as shown in the lower illustration, where *a* is the stone and *b* the drips. The coping should project $1\frac{1}{2}$ inches or 2 inches over each face of the wall. To prevent them from becoming displaced, horizontal coping stones are often clamped together at their ends, as at *c*. They may also be doweled together with metal dowels as at *d* or with stone dowels as at *e*.

The joints should be carefully filled to prevent water entering them. Cement mortar consisting of one part Portland

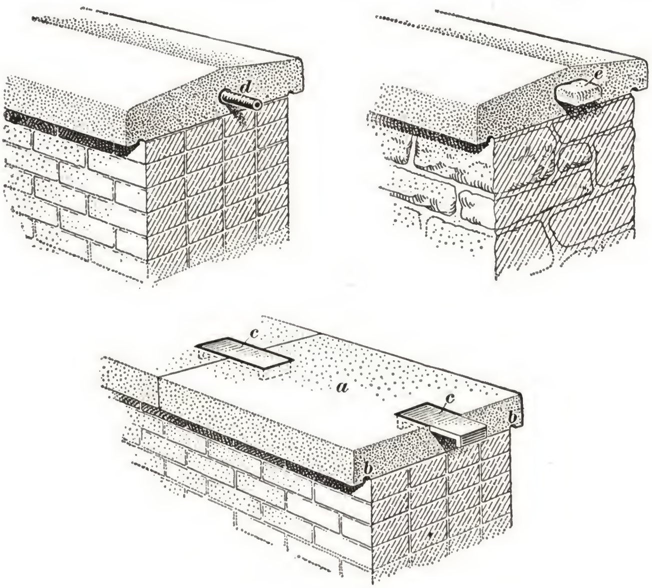


FIG. 32

cement and one part sand should be used and the joints finished off even with the surface of the coping.

34. Gable Copings.—Copings are used to protect the inclined upper surfaces of gable walls, as shown in Fig. 33. It is necessary to secure these stones to the wall very carefully, as there is a tendency for them to slide down the wall. They are secured by the use of *kneelers a, bond stones b,* and *anchors c.* The kneeler is cut with a long horizontal bed and prevents the section of coping *d* from sliding. The bond stone *b* is cut so

that it will extend into the wall and receive the end of the anchor *c*, which is turned down into the top of the stone. The other end of the anchor is turned up into the body of the gable wall. The coping stones are held together so that they cannot move sidewise by means of dowels *e*, which are made of pieces of metal rod, or else by clamps as shown at *c* in Fig. 32. The

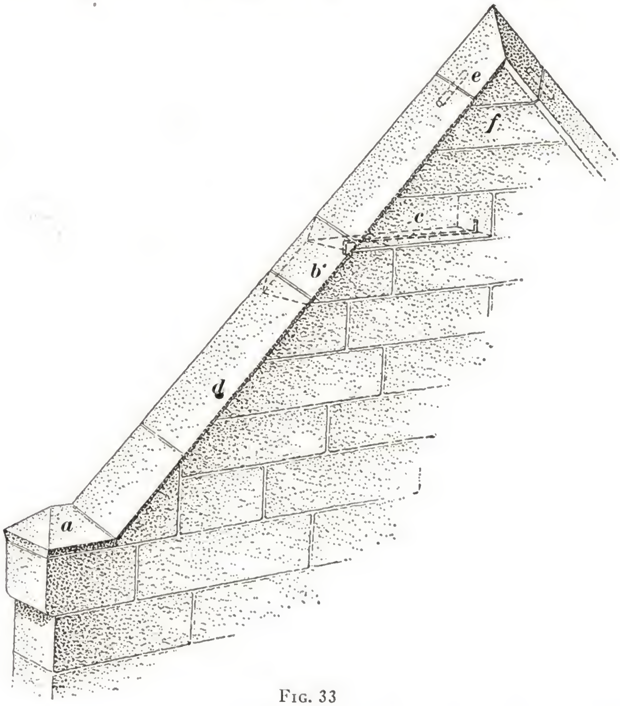


FIG. 33

fewer joints that are used in coping of any kind the better. Great care should, however, be exercised in bedding very long stones or they may break.

35. Gable copings need not be pitched on the upper surface, but should project for an inch or two over each face of the wall and have a drip at each edge so as to shed the rainwater. The coping at the point or apex of a gable wall is sometimes finished with a single stone which has a flat bed, as at *f*, Fig. 33, and is doweled into the stones on each side of the gable. A

finial, shown in Fig. 34, is sometimes used to terminate the gable when an ornamental effect is desired. This finial is cut

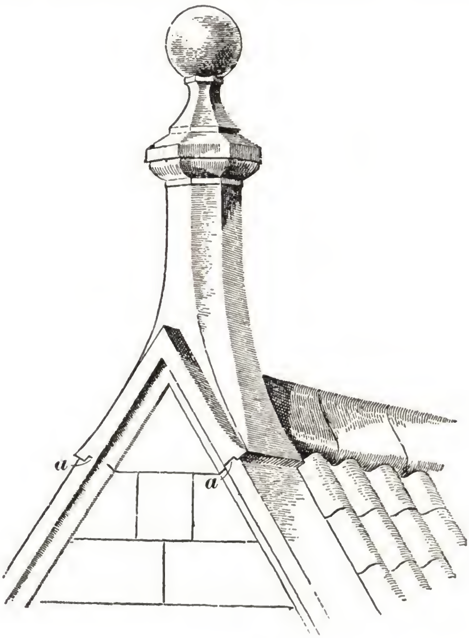


Fig. 34

out of one piece of stone and the two faces are sometimes grooved to receive the coping stones as shown at *a*.

COLUMNS AND ENTABLATURES

36. Columns.—Columns of stone that are not more than 8 or 10 feet in height are best made with the shaft in one piece, each shaft being a *monolith.* The capitals and bases are generally made of separate stones. Larger columns are made up of sections called *drums,* shown in Fig. 35 at *a, a.* The shafts of large columns that are intended for monumental purposes are sometimes made in one piece, or monolithic. This work is, however, very expensive and is not done except in monumental work.

When a column is to be formed of several pieces, the stones composing the different parts should be very carefully cut, having the beds between the cap, base, and shaft perfectly plane

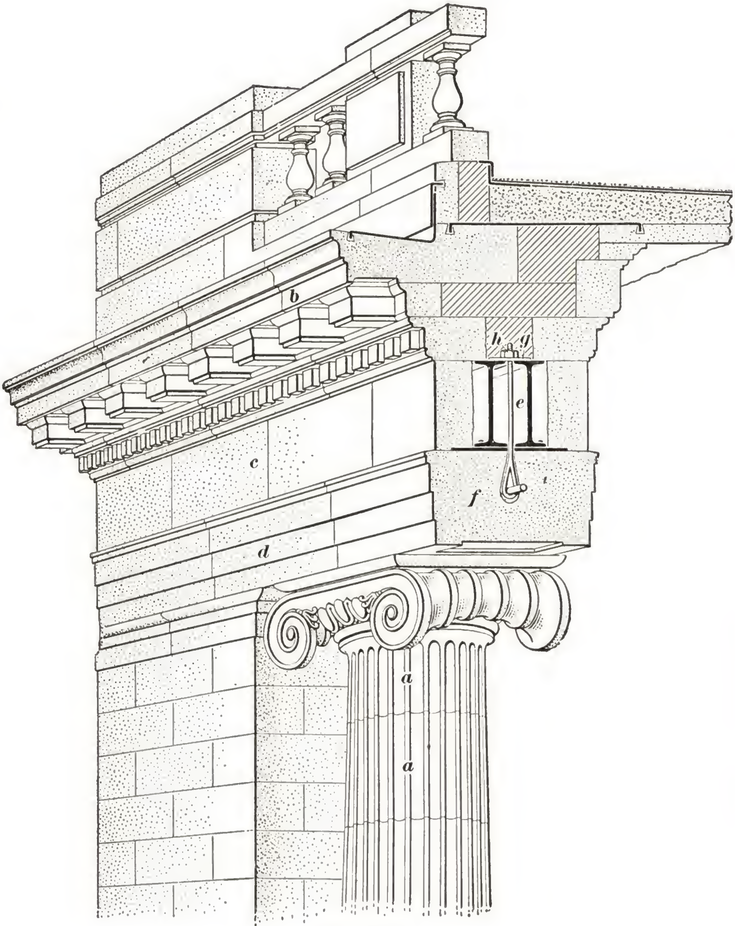


Fig. 35

and perpendicular to the axis of the column, in order that the pressure may be evenly distributed over the entire surface of the joints, also so that the stones shall fit exactly when put in place. For the joints, nothing but cement mortar should be

used, which should not be allowed to come within $\frac{3}{4}$ inch of the edge of the joint, in order to prevent the edges of the stones

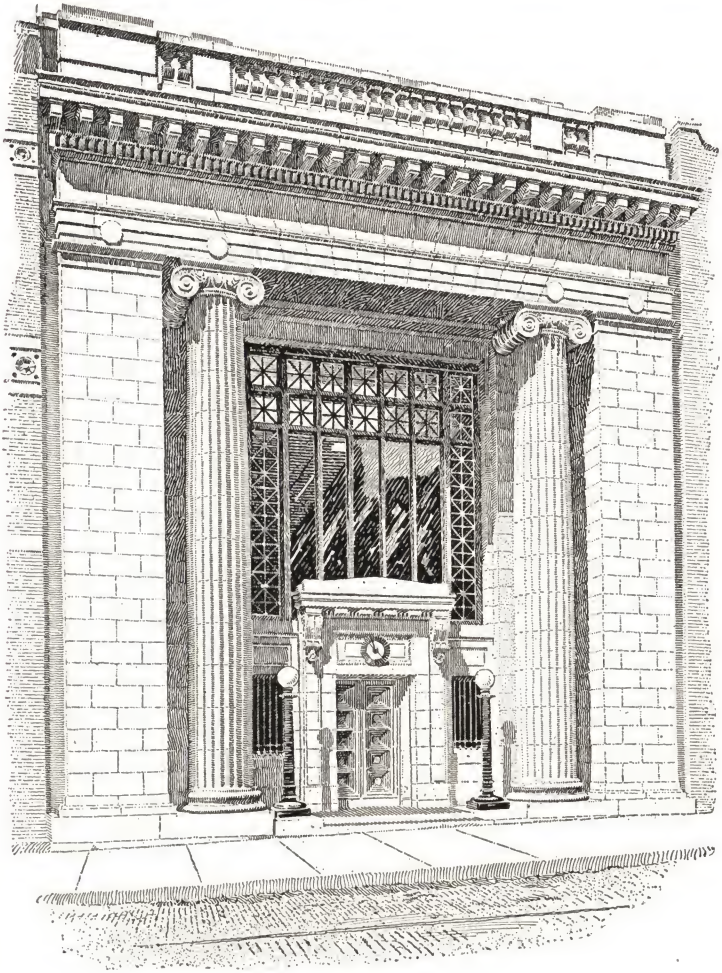


Fig. 36

from spalling. After the column has been finished for some time these joints are pointed up with strong mortar.

Columns generally have what is called an *entasis,* or swelling, in the shaft, as shown in Fig. 36, and must be laid out with

extreme care so that the drums shall fit together properly when the column is erected.

37. Pilasters.—A pilaster is a projection, rectangular in horizontal section, which projects from the face of a wall and has a capital and base similar to those of a column. Pilasters are tied into the masonry of the wall by extending occasional stones back into the wall.

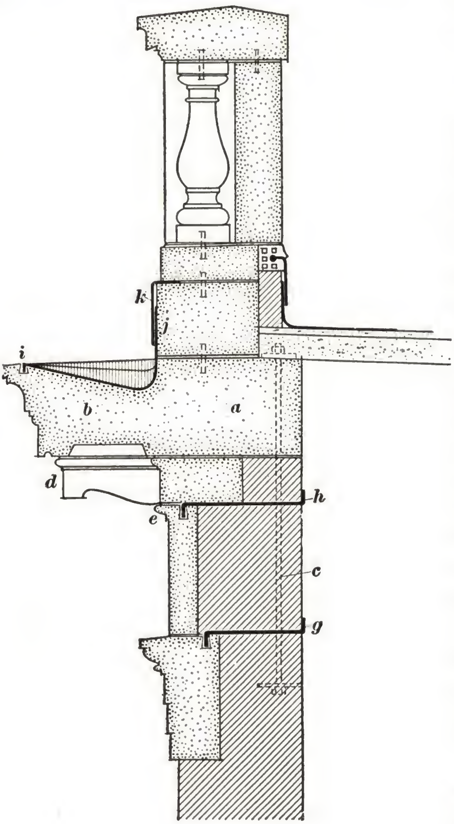


Fig. 37

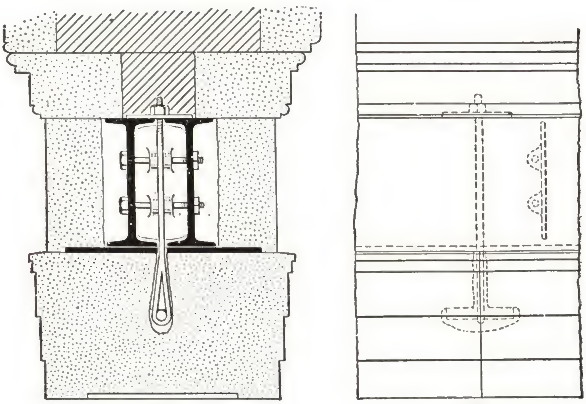
38. Entablatures. An entablature is an ornamental projecting band that crowns the building or some portion of the building, such as the main entrance or porch. It is generally used over columns and pilasters and consists of three parts, called the *cornice,* shown at *b,* Fig. 35, the *frieze,* shown at *c,* and the *architrave,* at *d.* The cornice has a projection about equal to its height and in certain cases is used without the other parts of the entablature.

An entablature such as is used on the face of a building is shown partly in section in Fig. 37. This cornice has a projection equal to its height and must be constructed so that the projecting part will not fall into the street. As a rule, these projecting stones are balanced by having at least an equal weight of stone extending into the

wall as shown at *a*. The weight of the portion of the stone *a* to the right of the face of the wall is slightly greater than that of the portion *b*. In addition to this precaution these stones are sometimes anchored down into the masonry by means of steel rods *c*, which extend up between the joints of the stones and down into the solid masonry and have steel washers on each end to form an anchor. The bracket course is shown at *d* and the bed moldings at *e*. The stones in the course *d* are held in place by being well balanced on the wall below and by the stone *a b* above.

The frieze is made of a thin stone which is held in place by means of the anchor *h*. The architrave is well supported and is anchored as shown at *g*.

39. An entablature acting as a lintel is shown in Fig. 35. The distance between columns is too large to be spanned by a



(a) (b)

FIG. 38

single stone, consequently a steel girder is used to support the entire entablature and balustrade above. This steel girder, consisting of two **I** beams, is shown at *e*. The stones of the architrave beneath are hung from the girder by rods which pass between the joints and are secured to bars or rods of steel that are let into the ends of the adjacent stones. The upper ends of the rods pass through small plates, as at *g*, and are held by nuts *h*, that are screwed up until the stones are supported at

the correct level. This construction is shown in detail in Fig. 38, in which a cross-section is shown in (a), and a section showing how the hanger supports the stones is shown in (b).

40. In Fig. 37 is shown one method of forming a gutter in the stone cornice. The stone is cut so as to form a gradual pitch from one end to the other and is lined with copper. The copper is left into a *reglet,* or groove, i and is held in place by calking with lead. The other edge is turned up against the surface j formed in the stone and a counterflashing k is brought down over the flashing.

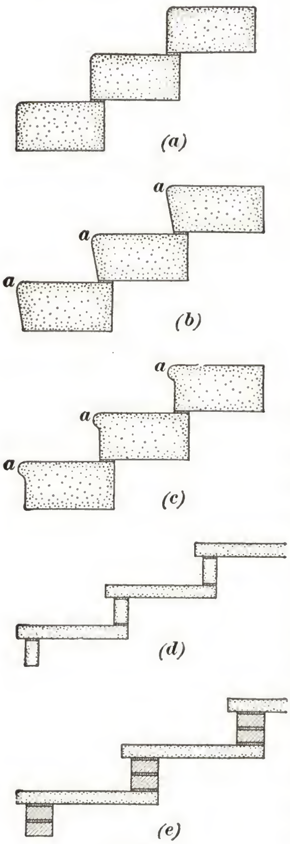


Fig. 39

STONE STEPS AND PLATFORMS

41. Stone Steps.—Stone steps are used as entrance steps for public buildings, schools, fine houses, and in other places where a monumental appearance is desired. They are also used in rustic work such as shown in Fig. 42 where suitable stones can easily be obtained. They should be made of the hardest stones obtainable, such as granite, bluestone, or marble. Limestone and sandstone are also employed where they are conveniently obtained, and they make serviceable and handsome steps. They show the effects of wear more quickly, however, than the harder stones do.

Stone steps, especially on public and monumental buildings, should be made of such a size that walking up and down them will be easy. A good average size for the tread is 12 inches and for the riser 6 inches. If the tread is narrower, the riser

should be increased in height. The steps will be easy if the height of the riser in inches multiplied by the width of tread in inches equals 72.

The steps should be finished with a slightly roughened surface so as to prevent slipping and should have a slight pitch downwards toward the front so that water will readily drain off them.

42. Forms of Steps.—Steps are made of solid pieces of stone, and of thin slabs. The solid steps are the best from the standpoint of appearance and service. Stone steps are made of blocks of rectangular sections, as shown in Fig. 39 (*a*), (*b*),

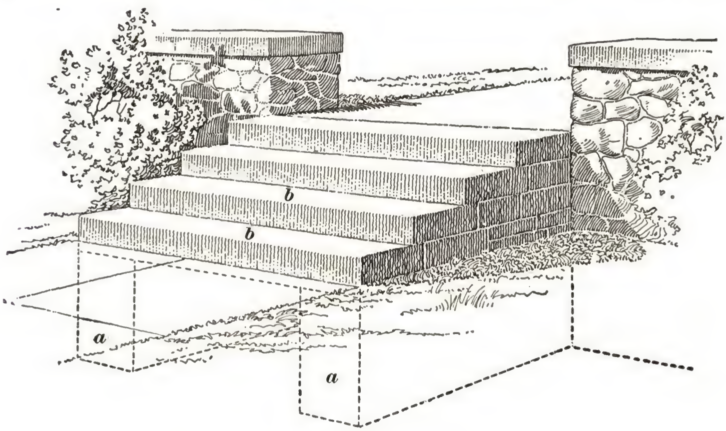


FIG. 40

and (*c*), and are finished square as in (*a*) or with *nosings* as shown at *a* in (*b*) and (*c*). Steps are formed of thin slabs of stone, such as marble, bluestone, etc., as shown in (*d*) and (*e*). In (*d*) the risers as well as the treads are formed of stone, which should be about 2 inches in thickness and held in place by having the ends inserted into side walls or else by being anchored to a backing. In some cases the risers are made of brick, as in (*e*).

In all cases the edge of the tread should be rounded off slightly and all the treads should be laid so that there will be a slight pitch downwards from the back to the front of the tread

43. Supporting Stone Steps.—Stone steps are supported in different ways. The simplest is upon walls that are built under the steps at each end and upon which the steps rest. This method is illustrated in Fig. 40, in which *a, a* are the walls supporting the steps *b*. The supporting walls must be started below the frost line and be built so that no settlement shall occur.

44. These walls are often carried up to form *cheek* walls as shown at *a* in Fig. 41. The ends of the steps are let into the cheeks from 4 inches to 6 inches so as to have a sufficient bearing.

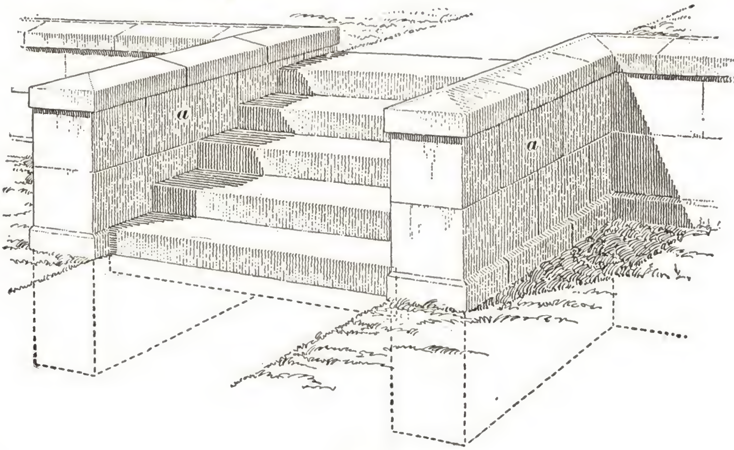


Fig. 41

When the distance between the bearing, or cheek, walls is more than 5 or 6 feet, it becomes necessary to make the steps two or more pieces in length. In this case intermediate walls are built to support the steps, as shown at *a* in Fig. 42. It is not desirable to provide only one intermediate support, as the joints of the steps would come too close together, hence two or more of these intermediate walls are built, depending upon the width of the steps, so that the joints may alternate over them as shown at *b, b,* etc. These walls should be not more than 3 or 4 feet apart.

In the example shown in Fig. 42 the treads are formed of slabs of stratified rock and the risers are of brick. Neverthe-

less the stone treads support the structure, since they extend under the brick risers and hold them up. This is illustrated at *c*, where an intermediate wall *a* is shown supporting the steps and the treads are shown resting upon this wall with brick risers on top of them. The pier *d* must be made of a size that will give support to the ends of the steps at *f*, and both the

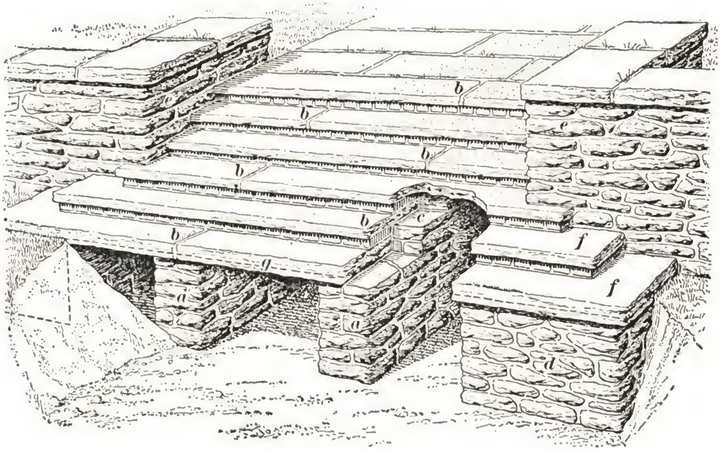


Fig. 42

piers and the walls should be begun below the frost line. Some of these steps are shown resting on cheek walls *e*, and some of them resting only upon walls *a*, *a* and *d*. The finished grade around the bottom step is indicated by the dotted line *g*.

45. In Fig. 43 is shown another method of supporting stone steps. The foundation for the steps, in this case, consists of cheek walls *a* for the ends and walls *b* and *c* under the top and bottom of the flight. An inclined reinforced-concrete slab *d* is supported on the walls *b* and *c*, and built up in the form of rough steps, as shown at *e*, to support the portion of the steps between the cheeks. This method is particularly useful when space beneath the steps is to be used for a storage or coal vault, as the slab *d* forms a good ceiling for such a vault as well as a support for the steps.

46. Platforms.—Platforms are formed between two short flights of steps and must in general be supported in a

similar manner to the steps. Platforms are generally of single slabs and these are sometimes of a good size, often as much as 6 feet square. They should not be made too thin, as they are liable to be broken in handling. The thickness of a solid stone platform should in general be equal to the height of a riser but should never be less than 5 inches.

47. Iron staircases are extensively used in fireproof construction. The treads, and sometimes the risers, are frequently

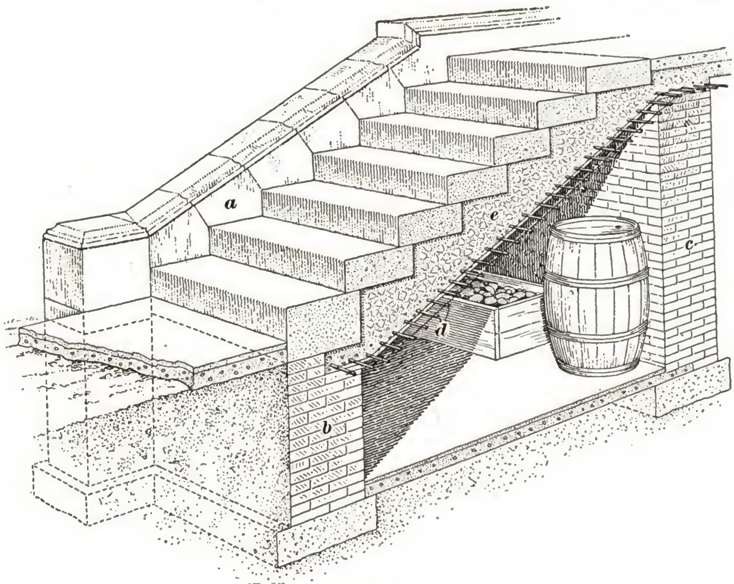


FIG. 43

marble slabs, while slate, which is cheaper, is also considerably used. When so used the stone treads should be set upon a sheet-metal tread so that if they are cracked or broken by the action of fire there will be a sheet-metal tread to walk upon.

STRING-COURSES, OR BELT-COURSES

48. A **string-course,** or **belt-course,** is a course of stone which generally projects or is ornamented in some manner so as to make a distinct horizontal band around the building

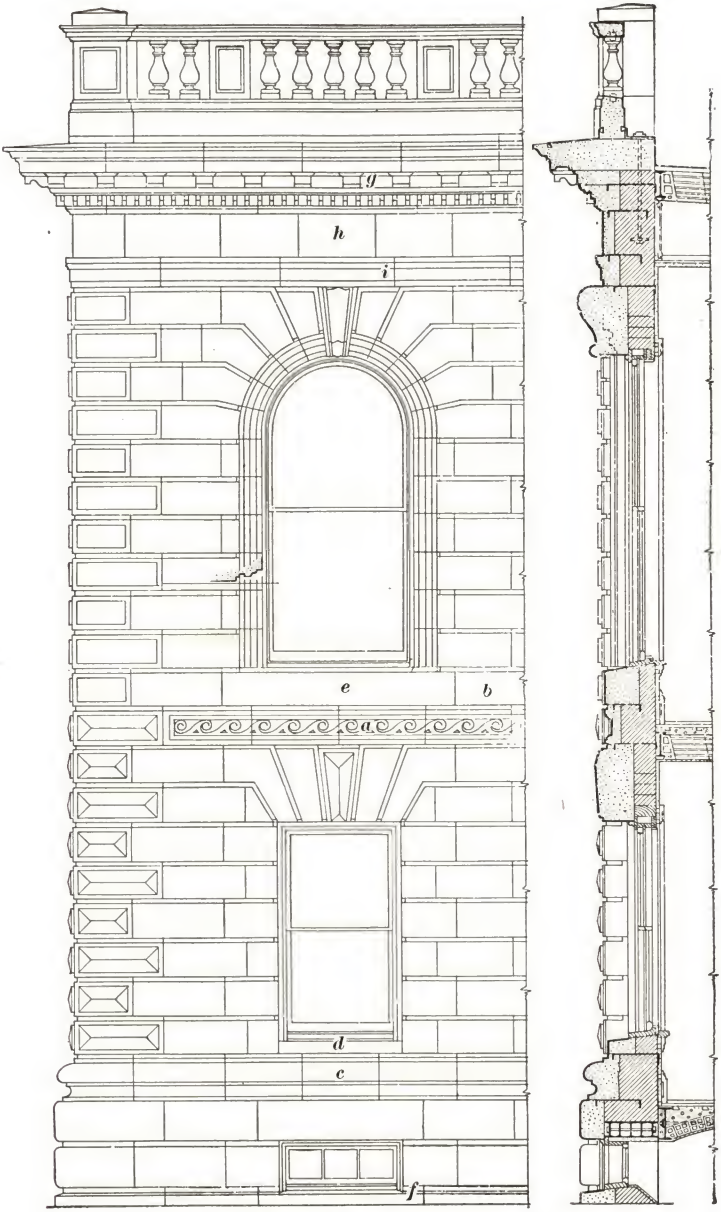


FIG. 44

or, in many cases, across the front of a building. Such a string-course is shown at *a* in Fig. 44. This string-course projects and is also ornamented and is carried around the building to mark the level of the second floor. The course *b* is what is sometimes called a *sill-course* since all the sills of the second-story windows are included in it. A string-course which is known as a **water-table,** and which forms the top of the basement wall, is shown at *c*.

This figure also illustrates several of the features of stone masonry that have already been discussed and shows their application to the façade of a building. The façade is faced with rusticated coursed ashlar. Ornamental quoins are shown on the corner of the building. A slip sill is shown at *d* and lug sills at *e* and *f*. An example of an entablature, consisting of the cornice *g*, the frieze *h*, and the architrave *i*, is shown. In the section the backing of the wall is shown by the hatched surface.

STONE ARCHES

49. Definition.—An **arch** is a masonry construction consisting of a series of individual stones which are used to

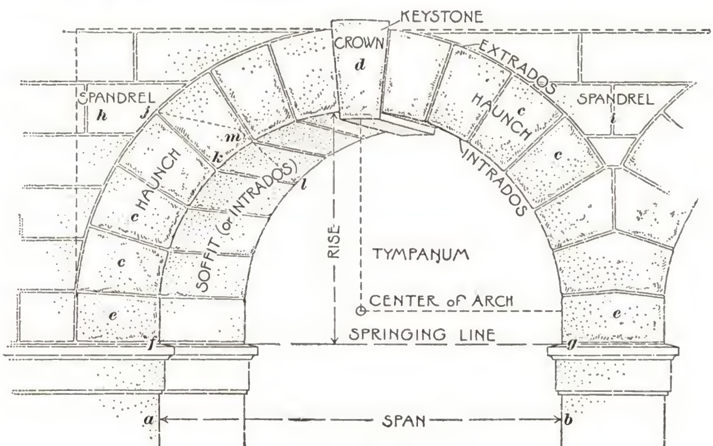


FIG. 45

span openings in walls or between piers or columns. Arches of various types are illustrated in Figs. 45, 47, 49, etc.

The general forms of arches are *semicircular, segmental. pointed, elliptic,* etc., the name being determined by the shape of the inner curve of the arch.

50. Parts of an Arch.—In order to obtain a better understanding of arches, the following definitions of the various parts of an arch are given. They may be readily understood by referring to Fig. 45.

Span.—The horizontal distance between the supports, as shown at *a b.*

Springing Line.—A line drawn through the points where the arch meets the abutments or supports, or where the vertical supports of the arch terminate and the arch begins, as shown at *f g,* Fig. 45.

Rise.—The perpendicular distance from the springing line to the highest point of the intrados.

Crown.—The highest portion of the arch.

Intrados.—The lower concave surface of the arch, formed by the under side of the stones, although considered by some authorities to be the concave line at the edge of the under side of the stones.

Soffit.—The lower surface of the arch, or the intrados.

Extrados.—The upper convex surface of the arch, formed by the outer sides of the stones in the arch; also, considered by some authorities as the convex line of the outside of the arch.

Arch Ring.—The arch itself, contained between the intrados and the extrados.

Skewback.—A stone in the abutment having an inclined face from which a segmental or flat arch springs. Skewbacks are shown at *a, a,* in Figs. 47 and 49.

Haunches.—The portion of the arch included between the crown and the springers.

Voussoirs, or Ring Stones.—The wedge-shaped stones *c,* Fig. 45, composing an arch.

Keystone.—The center or highest voussoir, shown at *d,* Fig. 45.

Springers.—The lower voussoirs, or bottom stones, *e* of an arch.

Tympanum.—The space between the springing line and the intrados.

Spandrel.—The triangular wall space *h,* Fig. 45, included between the extrados, a horizontal line drawn through the top of the extrados, and a vertical line drawn through the lower extremity of the extrados; or the space between two arches in an arcade, as shown at *i.*

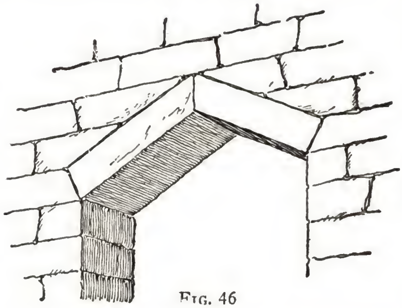


Fig. 46

Spandrel Filling.—The stonework filling the spandrel.

51. Stability of Arches.—The action of the load on the extrados of the arch presses all the voussoirs toward the center of the arch, which causes the voussoirs to press against each other. The surfaces under pressure, such as *j k l m,* Fig. 45, must be of sufficient size to sustain the pressure of the voussoirs upon each other. It is found in practice that an arch that looks well is generally of sufficient strength. An arch fails either by crushing of the stones or by the displacement of the stones due to unequal loading.

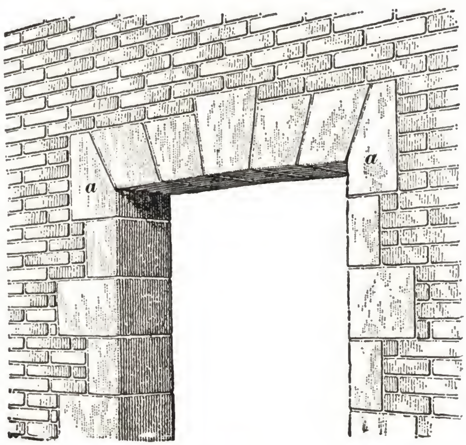


Fig. 47

52. Kinds of Arches.—Arches are named, from the form of the intrados, *semicircular, segmental, semielliptic, pointed, flat,* etc. The arch shown in Fig. 46 is an old and primitive form of arch. It is probably the first form of arch ever built.

53. Flat Arches.—The arch shown in Fig. 47 is known as a flat arch, and is very simple in design. This style of arch is used extensively over windows and other short spans where a flat soffit is desired, and very often in brick buildings. It will be noticed that all the voussoirs are wedge-shaped and that it would be difficult to force any one down out of its place. Although called a flat arch, it is usually built with a rise of $\frac{1}{8}$ inch per foot of span. For example, if a flat arch, such as shown in Fig. 47, has a span of 5 feet, the soffit will be $5 \times \frac{1}{8} = \frac{5}{8}$ inch higher at the center than at the sides of the opening. The rise in this case is $\frac{5}{8}$ inch.

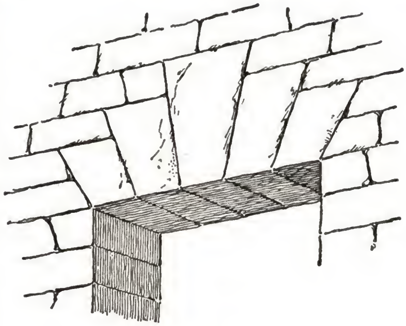


Fig. 48

This rise is to allow for any settlement that might occur in the arch. It also adds to the appearance of the arch, as an absolutely flat arch always has the appearance of sagging at the middle, whereas, a slight rise tends to neutralize this effect. A flat arch treated in this manner is said to be *cambered.*

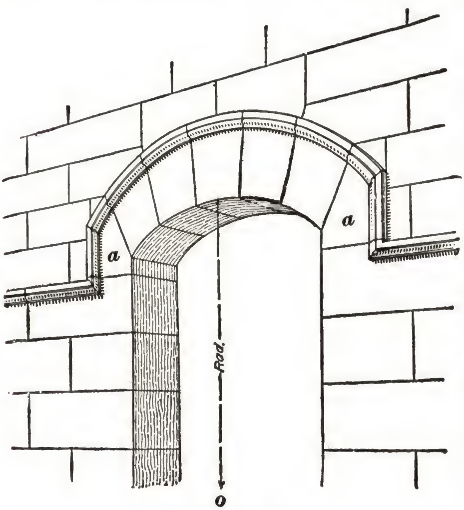


Fig. 49

54. Fig. 48 shows another style of flat arch, in which the voussoirs are of different sizes. There are other styles of flat arches used in practice, but they are all built on the same principle as those just described.

55. Segmental Arches.—If the intrados of an arch is in the form of a segment of a circle, as shown in Fig. 49, the

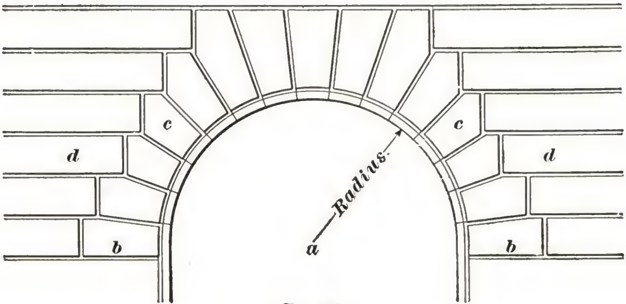


FIG. 50

arch is called a *segmental arch*. The curve of the intrados is struck from a center, as *o*. The point *o* is always below the

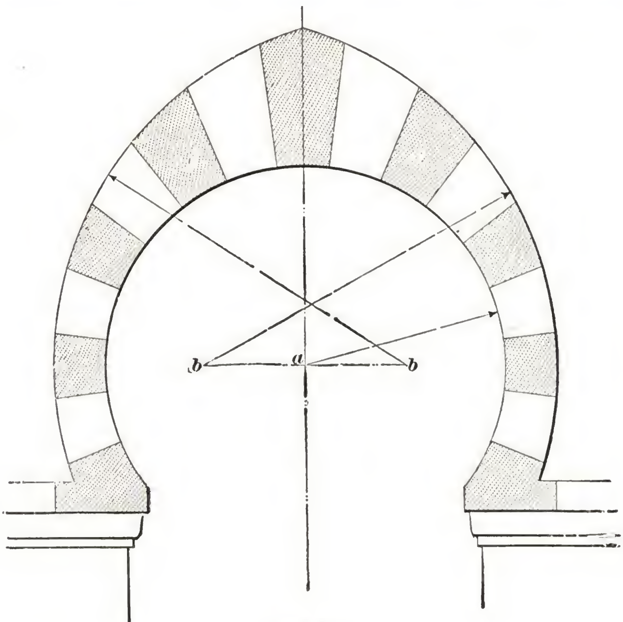


FIG. 51

springing line in an arch of this character, and the radius of curvature of the intrados is always greater than one-half the

span. The curve of the extrados is usually drawn from the same center as the intrados, although this is not necessary. In this example the arch springs from the skewbacks *a*.

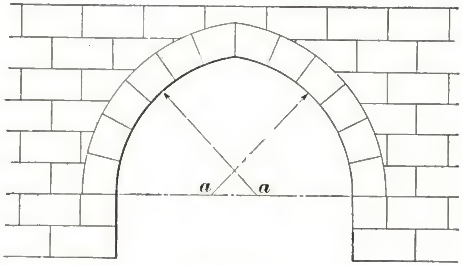


Fig. 52

56. Semicircular Arches.—When the intrados of an arch is a full semicircle with a radius equal to one-half the span of the arch, the arch is known as a *semicircular arch*. Such an arch is illustrated in Fig. 50. This type of arch is frequently referred to as a *circular arch*. In Fig. 45 the arch ring is of equal depth all around and the voussoirs are all of the same size, while in Fig. 50 the voussoirs are of different shapes. This is a matter of design only and has no particular constructional value.

57. Moorish Arches.—Fig. 51 shows an example of a Moorish, or horseshoe, arch. In this arch the intrados forms a curve that is greater than a semicircle. The centers of this

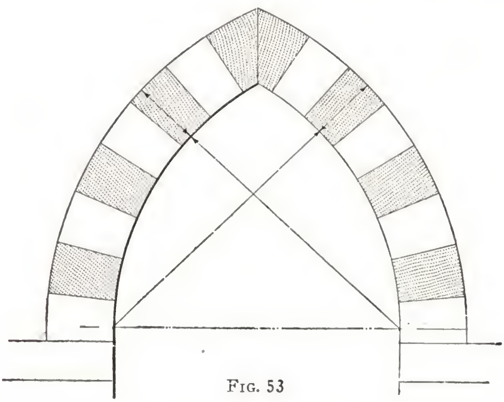


Fig. 53

arch are shown at *a* and *b*, *a* being for the intrados and *b* for the extrados.

58. Pointed Arches.—Pointed arches are illustrated in Figs. 52, 53, and 54. Fig. 52 shows a rather wide form of pointed arch that is sometimes called a *two-centered arch.* This arch has two centers, as shown at *a, a,* and the length of the radius is less than the span of the arch, and greater than one-half the span.

In Fig. 53 is shown what is known as an *equilateral arch,* in which the length of the radius is equal to the span of the arch.

59. The *lancet arch,* shown in Fig. 54, is one in which the radius is greater than the span of the arch, the centers generally being outside of the arch, as shown at *a, a.*

60. Semielliptic Arches.—Where the arch has an intrados in the form of a semiellipse, it is known as a *semielliptic arch.* It is also sometimes referred to as an *elliptical arch.* Such an arch is shown in Fig. 55. The following is a method of drawing an elliptical arch, also of finding the direction of the joints between the voussoirs.

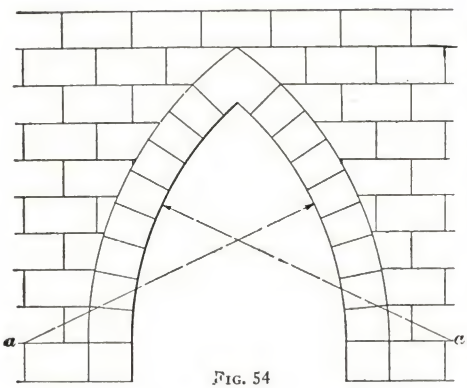


FIG. 54

To draw the intrados: Let *A B* and *C D,* Fig. 55, be the longitudinal and transverse axes of the ellipse. From *C* lay off *C e* and *C f* equal to *A O.* Through *e* and *f* drive two pins or small nails. Tie a piece of string to these two pins of such a length that it will reach to *C* as shown by the dotted line *e C f.*

Now by inserting the point of a pencil inside this string and moving it from *A* to *B,* at the same time keeping the string taut, one-half of the required ellipse will be described. The other half may be similarly described on the opposite side of the longitudinal axis.

The intrados of the arch is then divided off, generally into an odd number of parts of equal size, by the use of the dividers. Through these points the lines of the joints are drawn.

To find the direction of a joint: To find the direction of a joint at any point such as g, Fig. 55, draw straight lines from g to the foci e and f of the ellipse. A line $x\,g\,Y$ bisecting the angle $e\,g\,f$ will give the direction of the joint.

To bisect the angle: To bisect the angle $e\,g\,f$, lay off on the line $g\,f$ a distance $g\,e'$ equal to $g\,e$. Find the middle point x of the line $e\,e'$. Draw a line through x and g. This line will bisect the angle.

61. Three-Centered Arches.—A three-centered arch is an arch in which the curve of the intrados consists of the arcs

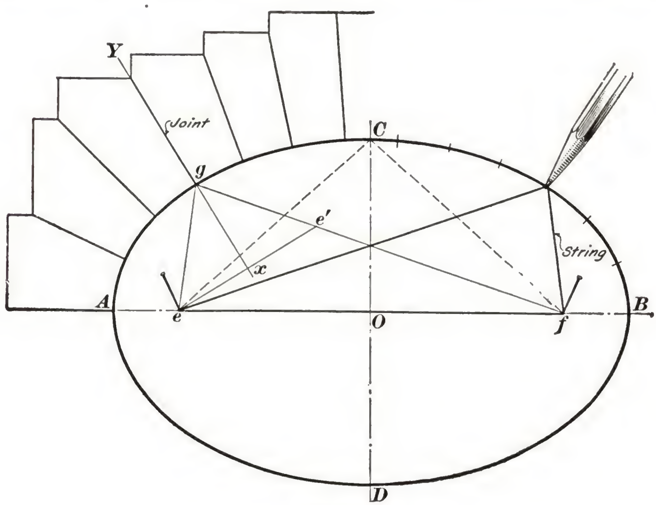


FIG. 55

of three different circles. To find the centers of these three arcs, divide the span $a\,b$, Fig. 56, into three equal parts, $a\,c$, $c\,d$, and $d\,b$. These three parts form the diameters of three circles as shown. Draw the vertical axis $e\,f$ of the arch. This will cut the circumference of the middle circle at e. From the point e draw lines through c and d, and extend them indefinitely. With c as a center and $c\,a$ as a radius, draw an arc inter-

secting the line through $e\,c$ at g. With d as a center and $d\,b$ as a radius, draw an arc intersecting the line through $e\,d$ at h.

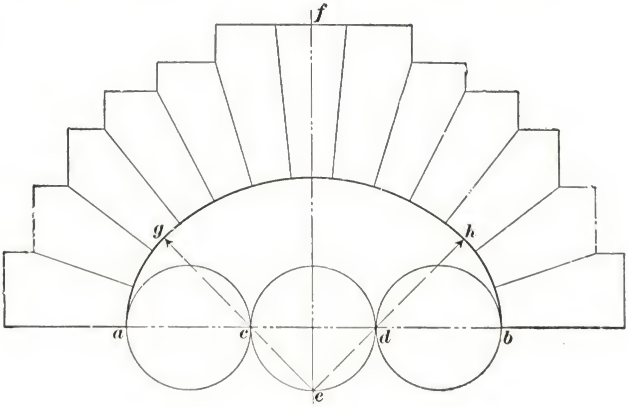


FIG. 56

The portion of the intrados between g and h is drawn with $e\,h$ or $e\,g$ as a radius and from e as a center.

The joints in the central portion are drawn from the center e, and the joints between a and g are drawn from the center c. The joints between b and h are drawn from the center d. It

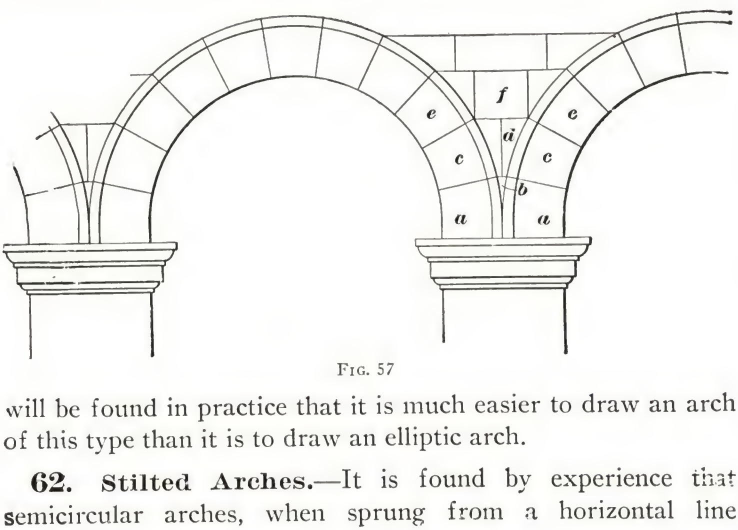


FIG. 57

will be found in practice that it is much easier to draw an arch of this type than it is to draw an elliptic arch.

62. Stilted Arches.—It is found by experience that semicircular arches, when sprung from a horizontal line

through the center of the arch, give the effect of the intrados being somewhat less than a semicircle, especially where the piers supporting the arch have large or projecting capitals, as shown in Fig. 57. It is therefore customary to have the center of curvature or center of the arch slightly above the springing line, as shown in Figs. 45 and 57. An arch treated in this manner is called a *stilted arch.* Fig. 53 shows another example of an arch that is stilted. Fig. 50 shows a semicircular arch in which the springing line is *b b,* and the center of curvature *a* is slightly above this line.

63. Construction of Arches.—An arch should be built of the very best kind of ashlar masonry, cut so that the vous-

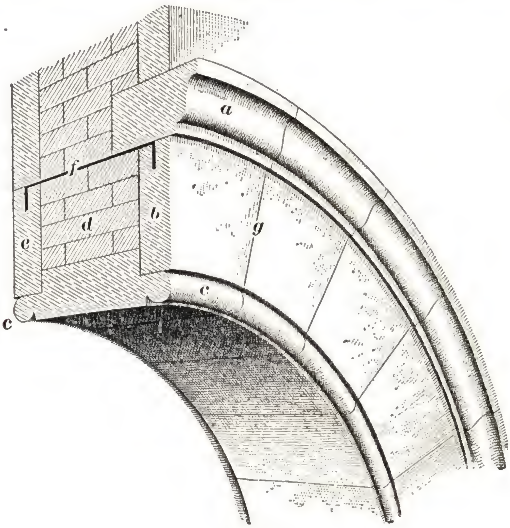


FIG. 58

soirs bear evenly and closely against one another with thin joints. The joints of the stonework should be of the same thickness throughout, so that bearing may be uniform over the entire surface of the joint. The thickness of the joints depends somewhat on the character of the finish. If the work is finely dressed, $\frac{3}{16}$ inch is the usual thickness, while in rock-faced work it is seldom made less than $\frac{3}{8}$ inch; $\frac{1}{4}$ inch is all that is usually allowed for the best work. Usually, the arch is divided

into an odd number of voussoirs, and in building the arch the keystone is placed in position last.

64. Backing.—As a rule, cut-stone arches in buildings are only from 6 to 8 inches thick, having a backing of brickwork or of a less costly kind of stonework. Large arches, especially when both sides are visible, as in entrances, porches, etc., are often constructed as shown in Fig. 58. In this case, the stone is backed by a brick arch *d,* and these are tied together with clamps *f,* which are fitted into the voussoirs *b* and *e.*

65. Bonding.—Whenever arches are carried on piers or columns, care should be taken in cutting the springers, so that

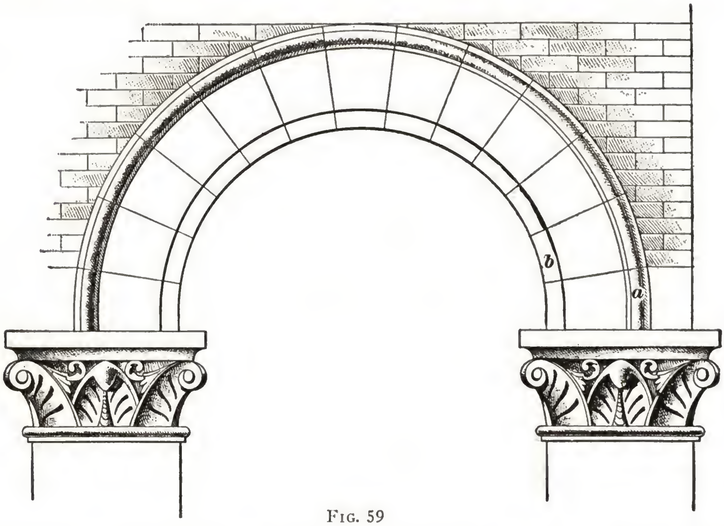


Fig. 59

they will bond properly into the masonry. Fig. 57 shows two arches sprung from a pier. The two springers *a* should be made of one piece of stone, so that it will not be necessary to fill up the space *b,* which would require a very small wedge-shaped piece of stone. The voussoirs *c, c* should be separate pieces and should be jointed at *d.* The voussoirs *e, e* would be separated by the stone *f.*

66. Moldings.—Arches are often decorated by the use of moldings such as shown at *a* and *b* in Fig. 59. These moldings

are sometimes cut on the voussoirs, and sometimes they are formed in separate courses, as shown in Fig. 58, which shows the method of constructing the arch shown in Fig. 59. A molding such as shown at *a*, Fig. 58, is generally called a *label molding*. The molding *c* is often referred to as a *soffit molding*.

67. Centers.—In building an arch, it is carried up from both piers, or abutments, at the same time. During construc-

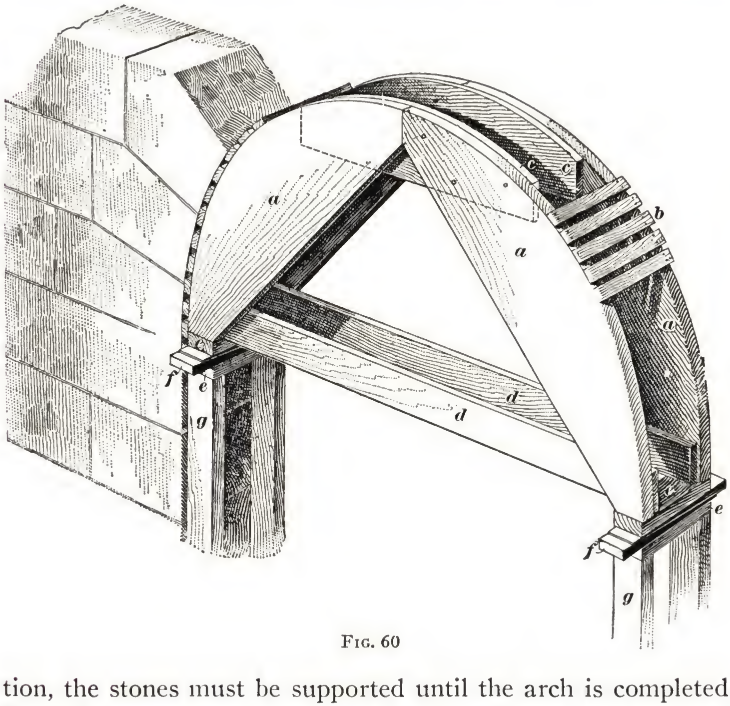


Fig. 60

tion, the stones must be supported until the arch is completed. For this purpose, as shown in Fig. 60, a framework made of planks cut to exactly fit the curve of the arch is used. This framing, known as a **center,** is supported on posts *g*, and the usual method is to insert wedges *f* between the center framing and the posts supporting it, which, when the arch has been completed and the mortar has set, are driven out gradually, so as to bring the load on the arch without shock. The center

should be strong enough to support the weight of the arch and a portion of the wall above, as no weight should be put on the arch until the mortar in the joints has become hard.

In Fig. 60 at *a* are shown the *bearers,* which are cut out of 2-inch plank and to a radius about 1 inch less than that of the intrados of the arch. At *c* are indicated pieces of plank, nailed at the crown of the center to splice and stiffen it. Small bearing strips *b,* about 1 in.×2 in. in section and known as *lagging,* are nailed to the curved pieces *a*. At *d* are shown longitudinal

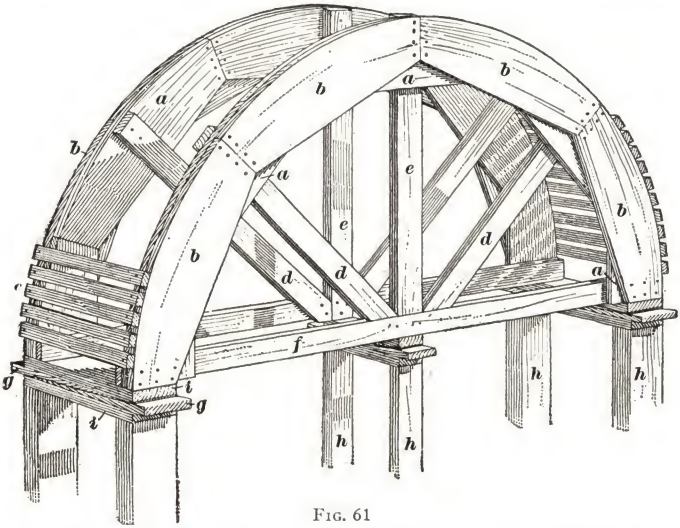


Fig. 61

braces; at *e,* the plates under the center and on top of the posts; at *f,* the wedges; and at *g,* the posts, which, if quite long, should be braced at the middle.

68. For arches of considerable span, centers more strongly built are necessary. Fig. 61 shows a good form of construction. At *a* and *b* are represented the *bearers,* breaking joint as shown; *c* indicates the *lagging; e,* the uprights; *d,* the inclined braces; *f,* the tie-piece; *i,* the bearing plates, with wedges *g* between; and *h,* the side and center posts. In building large arches, special care should be taken to carry up both sides of the arch equally.

SPECIAL STONES

69. Bond Stones.—Piers that have a horizontal cross-section of less than 9 square feet should be bonded at intervals of from $2\frac{1}{2}$ to 3 feet by having a bond stone built into them. These bond stones should be not less than 4 inches in thickness and should be cut with parallel and level top and bottom beds. They should also extend entirely through the pier. The brick or stone work upon which these stones rest should be brought to a level and the bond stone carefully bedded so as to bear as uniformly as possible upon all parts of the pier. The use of bond stones in constructing piers is required by the building codes of many large cities. Bluestone or granite or other hard stones are best to use for bond stones.

70. Templets, or Bearing Stones.—Where a beam, column, or a specially heavy load, rests upon a small part of a wall, hard stone blocks, called *templets* or *bearing stones,* are usually set under them in order to spread the load over a sufficient amount of surface of the wall below. The loads allowed by building codes are about 15 tons per square foot on brick masonry laid in Portland-cement mortar, and 7 or 8 tons on good rubble masonry laid in Portland-cement mortar. Hence, if a girder or column brings a load of 20 tons on a brick wall, the templet under the end of the girder must be $\frac{20}{15}=1\frac{1}{3}$ square feet in area, or 12 in.$\times$16 in. If the same load is supported on a rubble wall, the size of templet that will be required is $\frac{20}{8}$ $=2\frac{1}{2}$ square feet, or 18 in.$\times$20 in. These templets distribute the load from the narrow flange of the girder over a surface of wall sufficient to support it.

Templets must be cut with parallel beds, must be carefully set so as to have a uniform bearing, and should be of sufficient thickness so that they will not crack under the load. Bluestone, granite, or other hard stones are best to use for templets or bearing stones as these stones are generally subjected to great stresses or loads.

HANDLING AND SETTING STONE

71. Rubble stone is usually obtained from some convenient quarry and is conveyed to the building in wagons or carts. There is no particular care required in handling such stone, as there are no edges or corners that must be protected from injury. Ashlar, or cut stone, however, when cut to a finished shape at the quarry requires considerable care in handling to prevent its being damaged.

SHIPPING AND HANDLING CUT STONE

72. Packing.—Stone being very heavy is expensive to ship, and a decided saving in freight charges can be made by having the stones for a building cut approximately or even accurately to size before shipping. When this is done there is a risk that the finished edges and projecting members on the stones will be broken during shipment. It is therefore customary to protect the edges by strips of wood which are secured by means of metal straps nailed to the strips.

73. Cut stones are frequently conveyed from a local yard to a building in trucks, in which case they are laid upon strips of wood placed on the floor of the truck, and strips of wood are placed between the different stones, so that the stones cannot come in contact with each other. Straw or excelsior is sometimes used instead of wood strips between the stones. Great care must be exercised in placing stones on the truck as well as in removing them, so as not to chip the edges. A stone is practically spoiled if an edge that is intended to appear on the face of the building is spalled or chipped, and such stones are generally condemned by the architect and must be replaced.

Placing stones on and removing them from the truck is best done by means of a derrick, although on small jobs where there may be no derrick the stones are handled by several men who

move them about by using metal bars, rollers, etc. There is, however, considerable risk to the stone in this method of handling.

74. Delivery at the Building.—In delivering cut stone at the building it should be placed in a position where it will be protected from harm and should be arranged so that the stones can be reached in the order in which they are to be used. If the stones are to be placed on the ground adjacent to the building, they should have strips of wood placed beneath them so that they will not come into actual contact with the soil, as certain kinds of stone will become stained if they rest directly upon the soil. If they are not placed inside the building they should be carefully covered over with boards until needed in the building.

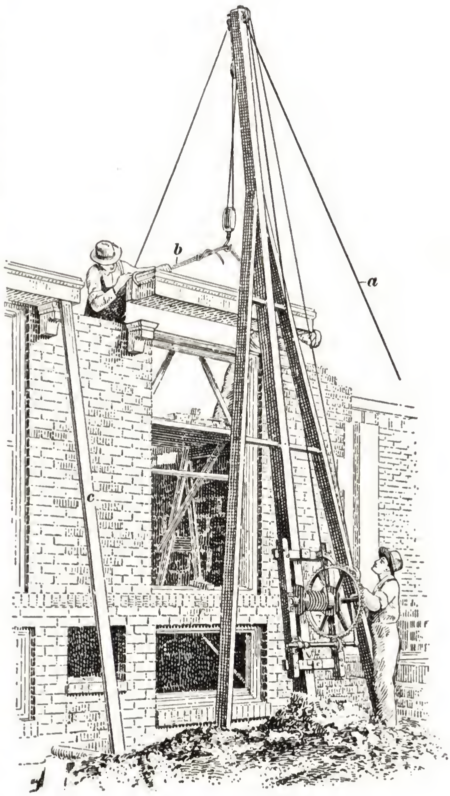


FIG. 62

In city buildings the stones are often hoisted directly upon a wooden bridge that is erected across the sidewalk. Upon this bridge they are trimmed and fitted if necessary before being hoisted into place.

75. Trimming.—It is often found necessary to refit some of the stones after they have been delivered at buildings. This work is done with hand tools. Sometimes the lewis holes and

other holes for attaching the stones to the hoisting apparatus are cut at the building. There is almost always a certain amount of cutting and fitting to be done at a building where much ashlar is used.

76. Raising Stones.—A stone weighing 80 pounds is as heavy as two men can handle successfully on a job. Derricks of some kind are necessary for stones heavier than this. For low buildings where the stones have to be lifted for comparatively short distances a derrick such as shown in Fig. 62 is used, the derrick being supported by a guy rope shown at *a*. One man can raise a stone of considerable weight with this derrick. The illustration shows a stone lintel being set in place. The stone has been raised to a short distance above its final position and is being slowly lowered into place. The man on the ground is operating a brake on the axle of the derrick which permits it to turn around very slowly. The stone is suspended from the ropes on the derrick by means of dogs, or grabs, small holes having been drilled into the ends of the stones and the points of the grabs inserted in them. They are held in place by the tension of the rope *b*.

In tall buildings of steel-frame construction the stones are set with a large boom derrick supported on the top floor of the frame or by smaller derricks attached to the steel columns of the frame. These derricks have booms which can be swung around as well as raised or lowered so as to deliver stones at any point on the front of the building as well as to lift the stone from the ground and raise it into place. These derricks are operated by a hoisting engine located on one of the lower floors of the building. Where only a few stones are to be set, derricks operated by man power may be used.

SETTING STONES

77. General Rules for Stone Setting.—In setting or putting together the stones to form a structure, the following principles or rules must be observed:

1. The vertical joints in any course should not come directly over the vertical joints in the course below.

2. Where the thickness of a wall is made up of two or more pieces of stone, bond stones or blocks that run through from face to face of the wall should be used whenever possible, for the purpose of binding the whole mass together.

3. Where the width of the wall is so great that a long bond stone would be liable to break, headers should be used at frequent intervals, should be placed as nearly over the center of the stretchers as possible, and should extend two-thirds across the wall, alternately from opposite faces.

4. When stratified stones are used, they should be laid on the natural bed; that is, the bed on which they rested in the quarry. Stratified stones when placed vertically are split and scaled by the action of the weather; moreover, a stone in this position has not as much strength to resist crushing as it has when placed with the lamina horizontal. Stones placed with their strata vertical can sustain only six-sevenths of the load borne by similar stones placed on the natural bed. When a stratified stone is used in a cornice with overhanging moldings, however, the natural bed should be placed parallel to the side joints; for, if placed horizontally, layers of the overhanging portions will be liable to drop off. (Precise directions for ascertaining the natural bed of a stone cannot be given. With some stones it is easy to distinguish; with others, it is a matter of extreme difficulty; in case of doubt, the quarry owners should be consulted.)

5. Every joint or space between the stones should be filled with mortar, and the spaces should be as small as possible.

6. The surfaces of porous stones should be moistened with water before being placed in contact with the mortar; otherwise they will absorb the moisture from the mortar, causing the mortar to become a crumbling mass.

7. For the sake of appearance, the largest stones should be placed in the lower courses, the thickness of the courses gradually decreasing toward the top.

8. The rougher the beds and joints, the better the mortar should be. The principal office of the mortar is to equalize the pressure, and the more nearly the stones are dressed to closely fitting surfaces, the less important the quality of the mortar;

with rough beds, the best quality of mortar should be used. This rule is frequently incorrectly reversed; that is, with fine, smooth, dressed beds the best quality of mortar is used. When using stones that have been sawed, it may be necessary to roughen the surface of beds and joints with the point or tooth ax, so that the mortar will adhere.

9. Porous stones should not be placed at or below the ground line.

10. In foundations, absorption of moisture from below should be prevented by placing a course of material that water will not penetrate at or near the surface of the ground.

11. Porous stone should not be employed for copings, cornices, window sills, or other parts of a structure where water is likely to lodge.

12. In setting cut stones, as sills, water-tables, belts, etc., the mortar should be kept back about 1 inch from the face, the space being filled when the pointing is done.

13. If a stone that has once been set requires to be moved for any reason, it should be lifted clear from the mortar bed, the mortar removed, and the stone set in a new bed of mortar in the new position.

14. Hammering or cutting stones on the top of stones just set in the work should not be practiced.

15. All courses that project beyond the general lines of the wall, as sills, lintels, belt-courses, etc., should be covered with boards or otherwise protected from damage.

78. Protection Against Staining.—Certain kinds of stone, such as Indiana limestone and some sandstones, which are used in great quantities, are more or less absorbent, and when brought in contact with cement mortar in the wall are apt to become stained. To avoid this, the backs, joints, and beds of the stones are given a coating of non-staining Portland-cement mortar. This coating is applied before setting the stones, and closes the pores of the stone. This prevents water that contains materials that would discolor the stone from working through the stone and appearing on the face. The stones are coated to within $\frac{3}{4}$ inch of the face, leaving room for

the pointing mortar, which will be applied later. Plaster will adhere to the cement coating, thus making it possible to apply plaster directly to the backs of the stone without the use of furring and lathing. The adhesion of mortar to the coating is also perfect.

79. Mortar for Ashlar.—The mortar for ashlar should consist of one part hydrated lime, or lump lime paste, one part non-staining Portland cement, and from four to six parts clean sand, all by volumes.

The mortar is sometimes kept back of the face of the wall for a distance of $\frac{3}{4}$ inch, or the joints may be flushed full of mortar and immediately raked out, to be pointed later. For pointing mortar the customary proportions are 1 part non-staining cement to from $1\frac{1}{2}$ to $2\frac{1}{2}$ parts fine white sand, with about 15 to 25 per cent of lime added to obtain the desired plasticity and working quality. One part of non-staining cement to from 1 to $1\frac{1}{2}$ parts of fine white sand, by volumes, are the usual proportions for grout to fill thin vertical joints.

80. Wedges.—The thickness of the joints is important in ashlar and in order that they shall be made of an exact thickness, small wooden wedges are laid in the joints so as to regulate this thickness. These wedges are left in place until the mortar has set, when they may be removed.

81. Use of Pinch Bars.—Pinch bars are small bars of steel, similar to crowbars, with sharpened points, which are used in moving stones, especially ashlar. The use of pinch bars on the joints around the face of the stone should not be allowed, as there is a risk of spalling the stone. Pinch bars may, however, be used at the back and sides of the stones without danger.

82. Leveling, Plumbing, Etc.—The stones should all be set with level beds and plumb joints for straight ashlar, and should be carefully tested before the stone is considered as finally set. The testing is done by the use of a plumb rule and a level.

83. Anchoring, Clamping, and Doweling. **Anchors** are used to fasten ashlar to its backing. All anchors

should be of galvanized iron and should receive one or two coats of approved waterproof paint before being put in place in the wall. They should extend down into the top of the stone at least $\frac{3}{4}$ inch and up or down into the backing about 2 inches. The holes for the anchors in the stones should be not less than 2 inches in from the face of the stone and should be spaced about 2 feet apart.

FIG. 63

84. Clamps are used in fastening coping stones together as previously described and shown in Fig. 32. They are let into the tops of adjacent stones, are countersunk, and fastened in place by cement or melted lead.

85. Dowels are pieces of metal bar or of stone let into two adjacent pieces of stone to keep them in alinement or keep them in a fixed position with regard to one another. Fig. 63 shows a finial in which the upper portion is doweled to the lower portion by means of a dowel *a*. This dowel, if of metal, should be of brass or copper, but as these metals are very expensive, galvanized iron is generally used.

A stone dowel is shown in Fig. 32 at *e*, where it joins two sections of coping together. Stone dowels are fastened in the sockets by the use of strong cement mortar.

86. Bracing.—Projecting stones are sometimes held up temporarily by means of wooden braces, as at *a*, Fig. 64. These braces are often necessary until the mortar sets and

hardens, to prevent the projecting end of the stone from sagging while the mortar is soft. In Fig. 62 is shown a brace *c*, supporting a window cap until the mortar hardens.

87. Protection From Damage.—As fast as the stonework is set, all window sills, string-courses, and exposed portions of cut stonework that are liable to damage by objects falling upon them should be carefully boxed or covered with boarding securely fastened in position and should be kept covered until the likelihood of damage has passed.

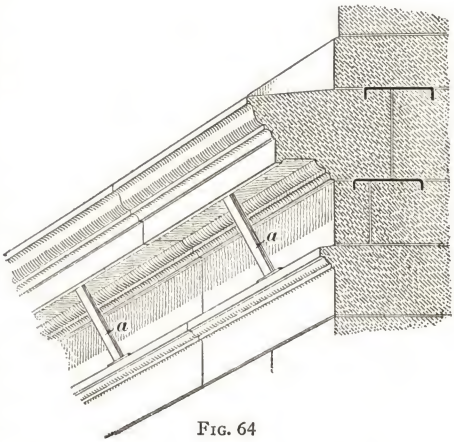


Fig. 64

88. Pointing. The purpose and methods of pointing have already been described. The durability and good appearance of stonework depend largely on proper pointing; therefore, special care should be taken to see that it is well done.

89. Cleaning.—While pointing, it is customary to remove the mortar stains, etc. from the face of the wall. This may be done with soap powder boiled in clean water and applied vigorously with a stiff fiber brush. If necessary, clean, sharp, white sand may be added to the mixture. The stonework should be scrubbed until all mortar stains are removed. After cleaning, all exposed surfaces should be drenched with clean water.

For cleaning granite, wire brushes are sometimes used, but should never be used for limestone or sandstone.

The sand blast, worked by either steam or compressed air, does the work of cleaning walls very effectively and rapidly; it removes the outer layer of the discolored stone, and leaves a fresh, bright surface. Even fine carvings have been very successfully cleaned by this method.

STRENGTH, MEASUREMENT, AND INSPECTION OF STONEWORK

STRENGTH OF STONE MASONRY

90. The strength of stone masonry depends upon the shapes of the stones used, the manner in which they are laid,

TABLE I

SAFE LOADS ON STONE MASONRY ACCORDING TO LAWS OF DIFFERENT CITIES

Kind of Masonry	Kind of Mortar	Boston	New York	Chicago	St. Louis	Seattle	Davenport
		Load, Pounds per Square Inch					
Rubble, Ordinary.......	Portland Cement	...	140	...	100	100	140
Rubble, Ordinary.......	Lime and Cement	...	110	...	85	...	100
Rubble, Ordinary.......	Lime	...	...	...	60	60	70
Rubble, Coursed........	Portland Cement	...	...	200	200	200	...
Rubble, Coursed........	Lime	...	...	100	120	120	...
Granite—Ashlar.........	Portland Cement	834	800	400	600	800	600
Limestone—Ashlar......	Portland Cement	556	500	400	400	400	600
Sandstone—Ashlar......	Portland Cement	417	300	400	...	200	300

and upon the quality of the mortar used. Thus, ordinary rubble masonry composed of irregular-shaped stones, in which the spaces between the larger stones are filled with spalls and lime mortar, is very weak when compared with a wall built of the same stone finely cut, carefully bonded, and laid up in Portland-cement mortar.

Table I gives the loads per square inch that are allowed on masonry of various kinds by the building laws of several cities in the United States. These loads represent good prac-

TABLE II

SAFE LOADS ON STONE COLUMNS

Kind of Stone	Load per Square Foot Tons
Sandstones—	
Potsdam, New York, best	40
Longmeadow, Massachusetts, best	35
Manitou, Colorado, best	25 to 30
Ohio	25
Fond du Lac, Wisconsin	25
Limestones—	
Glens Falls, New York	35
Indiana	25 to 35
Marble—	
Good quality	40

tice and must be observed by architects and contractors working in those cities.

The loads given for granite, limestone, and sandstone ashlar are for walls built of carefully squared blocks of stone set in Portland cement and well bonded together.

91. Strength of Stone Columns.—A column of good stone that is carefully set and has well-dressed bearing surfaces should, if its height is not over ten times its diameter, safely carry a load about one-fifteenth of the crushing load of

stone of the same quality. Table II gives the safe bearing values for different kinds of stone columns when the shaft consists of a single piece.

MEASUREMENT OF STONEWORK

92. Dimension Stone and Rubble.—At the quarry, stone is divided into two classes: *dimension stone* and *rubble*. **Dimension stone** consists of those pieces that are quarried in regular shapes, and to a fixed size; they are usually 4 square feet or more in area and over 8 inches thick. This class of stone is usually sold by the cubic foot, and costs about three or four times as much as rubble. In some cases rubble is the only product of the quarry and in others it is a secondary product to the dimension stone.

Rubble includes pieces of various sizes and shapes. It is suitable for work in which the courses are 12 inches or less in height and the stones are not over 24 inches long. Generally speaking, all stone not quarried to a certain size may be termed rubble. Rubble stone is usually sold by the carload, or in small quantities by the perch, and in some localities by the ton.

93. Measuring Methods.—Footings built of dimension stone are generally measured by the square foot. If built of large rubble, or irregular stones, the footings are usually figured in with the walls, with allowance for the extra width. Rubble is usually measured by the perch, which varies from 16 to 25 cubic feet, being $24\frac{3}{4}$ cubic feet in the Eastern States, $16\frac{2}{3}$ cubic feet, by custom, in Colorado, and 22 to 25 cubic feet in various other places. A necessary precaution when work is to be measured by the perch is to agree on the number of cubic feet in a perch, and also in regard to deductions for openings. If this is not done, the custom of the particular locality will probably govern in case of disagreement. In some places, rubble work is measured by the cubic yard of 27 cubic feet or by the cord of 128 cubic feet. Stone backing is commonly figured the same as rubble. In measuring rubble walls for estimating, the corners are counted twice so that the extra labor of plumbing and cutting them will be provided for. In

other words, the length of the wall is measured to the extreme edge of the wall on both sides.

94. Ashlar masonry is almost invariably measured by the square foot, the cost depending on the kind of work and the size of the stones. It is usual to deduct openings in ashlar work; when the width of the jambs of windows is more than the depth of the ashlar, the jambs are usually measured in with the facework. Flagging and all thin pieces or slabs are also figured by the square foot.

Moldings, belt-courses, and cornices are usually measured by the linear foot, but if the shapes are not regular they are figured by the cubic foot. All carved work is estimated by the piece.

Trimmings are sometimes figured by the cubic foot, the price varying with the amount of labor required in dressing. Probably the most accurate way of figuring this class of work is first to estimate the value of the rough stone and then that of the labor involved in the different classes of work, the resulting prices being per linear foot. This method is the one usually employed in figuring granite work

---

INSPECTION

95. The inspector or superintendent should be very careful to have the work properly done during erection—both the cutting and the setting of the stone—for if an imperfect piece is once set in place it cannot be removed without considerable trouble. The stones must also be carefully examined, as otherwise many cracked and defective ones may be used, either by accident or design.

96. Stone Defects.—Granite may contain cracks, black or white lumps known as *knots,* and a brownish stain called *sap*. When such defects are found, the stone should be rejected, if the importance of the work justifies it. Cracks are the main things to guard against, however, and they may be detected by the absence of the clear ringing sound when the stone is struck with a hammer.

Sand holes are frequently found in sandstones. These are bodies of uncemented sand that become dislodged by jarring or by the action of water and produce a pitted appearance and an uneven color. Attention must also be paid to securing uniformity of color, as sandstone from different parts of the same quarry may vary greatly in this respect.

97. Patching.—Patching is often resorted to when a piece has been broken from a stone. Instead of using a new stone, the old one is patched by gluing on the spall with shellac, the joint being hidden by rubbing stone dust over it. Rain, however, will wash out the shellac. There are times when a patch is allowable, as, for example, when a new stone cannot be had without great expense and delay. In such a case, the superintendent may permit patching to be done, but care should be taken to put on the spall by inserting it, when possible, in a square hole, or dovetailing it in such a way that it will not become displaced.

98. Faults in Dressing Stone.—The common faults of cut stone are coarseness and poor workmanship. Frequently, the ends of cornices, belt-courses, etc. will not properly match. It should be strictly required that the utmost care be taken in cutting all similar pieces to the same pattern, and that the abutting surfaces be closely dressed. In case these courses do not match they should be cut so as to remedy this defect after they are set in place.

99. Laying Stonework.—In erecting stonework, care should be exercised to have the stone set on the natural bed, with good joints, and not in too small nor in too thin pieces. The bed joints in ashlar work should be perpendicular to the face of the wall, and not less than 4 inches wide at both top and bottom. The proper bonding of the walls should be given very careful attention, as well as the placing of lintels, copings, wall anchors, etc.

Another point that requires attention is the formation of the joints on which great pressure comes; the mortar should be kept back from the face, so that the edges of the stones will not be chipped off.

SIDEWALKS

100. Definition and Purpose.—A sidewalk is a prepared footway placed at the side of a roadway for the use of pedestrians, and is usually separated from the roadway by a curb and gutter. It is generally finished with a hard, durable surface consisting of brick, stone, or concrete, and is formed with a suitable slope so that rainwater will run off it readily.

101. Building Laws.—As sidewalks are used extensively by the public, the building laws usually define the details of construction that are considered necessary to make them safe for the use of pedestrians. Some of the requirements that are common to many of the codes are the following.

Sidewalks over vaults shall be designed to be of sufficient strength to sustain safely the live load that they are required to carry.

Sidewalks shall be formed with a slope to drain away water. This slope shall not be greater than $\frac{1}{4}$ inch to 1 foot.

Sidewalks shall be formed with a rough surface that will afford a secure footing for pedestrians.

In addition to code requirements there are often city standards for the construction of sidewalks that also must be complied with.

102. Stone Sidewalks.—Sawed or split slabs of stone make an excellent sidewalk and are used extensively where such material is easily obtained. The best stone for this purpose and one that is most generally used is bluestone, although any compact limestone or granite will answer the purpose. The objection to granite, however, is that is wears very smooth and thus becomes slippery when it is wet.

Flagstone sidewalks for residential districts are usually formed of slabs that extend the entire width of the walk. These slabs are from 2 to 4 inches in thickness and the edges that are to adjoin are cut true and even to form close joints. The edges that form the sides of the walk are usually not dressed, but after the walk is laid they are cut to a line on the surface, the remaining part of the edge remaining rough.

Foundations for flagstone sidewalks are usually made of sand or cinders, and the depth of this foundation should be determined by the climatic conditions of the locality where the walk is to be laid. A very shallow bed of sand will suffice where there is no frost to affect the soil, but where cold weather occurs the bed should be from 4 to 12 inches deep to provide suitable protection for the walk.

103. Flagstone sidewalks for business districts are usually formed of large slabs so that there may be as few joints as possible. The slabs should be of ample thickness, as the excessive use of these walks causes the stone to wear away rapidly.

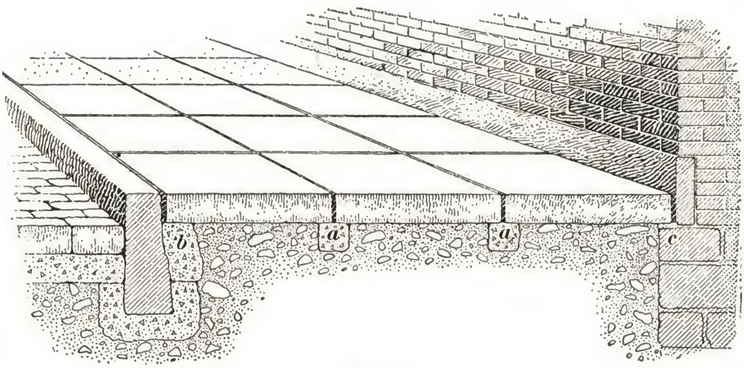


FIG. 65

Where these slabs form the roofs of vaults they are often made from 6 to 8 inches in thickness, this thickness being determined by the kind of stone that is used, the span between the bearings, and also by the live load the slab is required to carry. Walks of this character when resting on soil should have foundations similar to those described for residential districts.

Wide sidewalks that are formed of a number of slabs should be provided with foundations that will maintain the slabs in a level position at all times so that one slab may not project above or settle below the one adjoining and thus cause pedestrians to trip and fall. Slabs laid on the soil may be maintained in position by installing shallow concrete walls under each joint as shown in Fig. 65 at *a*. Slabs that adjoin the curb

should rest on the curb wall where such a wall exists or on a shallow wall as shown at *b*, while those which adjoin the foundation of the building should rest on either the foundation wall, as shown at *c*, or a shallow wall similar to those installed at the joints.

All joints between stone slabs, also the joints at the curb and wall lines, should be carefully filled with oakum and cement mortar. The process consists of placing oakum in the joint and driving it down by means of a hammer and a thin tool until it forms a compact filling to within 2 inches of the top of the slab. The remaining part of the joint is then filled with a mortar that is rich in cement. Hot asphalt, or asphaltic cement, is sometimes used in place of the cement for the filling, but it does not have the wearing value of the cement and will require replacing every few years if these joints are to be kept waterproof.